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Thermal Swing Adsorption in a Carbon Capture System

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Abstract
In the last years, the post-combustion capture of CO_2 based on physical adsorption has been extensively studied in terms of economy, ecology, and process efficiency. The industrialization of the process involves the construction of adsorption columns in which adsorption and desorption mass transfer occurs. Each one solid-gas system has individual mass and heat transfer properties. In this study, the adsorption and desorption processes in the fly ash zeolite (FAZ) - CO_2 system were investigated in dynamic conditions. The breakthrough curves were built performing series of experimental measurements under varying conditions in order to establish the optimal desorption temperature. Multiple adsorption/desorption studies were performed in the temperature range 50-200 ^oC at the maximum leakage concentration of 5 vol % CO_2 in the exhaust gas stream versus the time. The small variation in the adsorption capacities achieved and the minimal deviation in the break point determine suitability of the FAZ-CO_2 system for low thermal swing adsorption process at 50 ^oC.
Keywords: fly ash zeolite, adsorption, carbon dioxide, carbon capture

1. Introduction

In the last years, the fast development of the carbon capture technologies is due to the increased CO_2 levels in the atmosphere. Among all industries responsible for the CO_2 emissions, the production of electricity combusting organic fuels has the biggest share. The technologies for CO_2 reduction with an industrial application potential are developed in three directions: pre-combustion capture, oxy-fuel, and post-combustion capture (PCC). The main challenge in front of the carbon capture technologies is the technical and economical efficiency of the CO_2 separation processes. In this aspect, PCC is considered as the most suitable technologies for implementation to the existing Thermal Power Plants (TPP) (Wang et al.). The most widely studied approach is the PCC based on the CO_2 chemisorption by amine-based solutions. The industrial application of this technology suffers from the high energy consumption for desorption process (Gruenewald and Radnjanski). This disadvantage could be overcame by applying physical instead of chemical CO_2 capture. The physical adsorption of CO_2 onto solids could be realized in industrial scales as pressure swing adsorption (PSA) or thermal swing adsorption (TSA) depending on the driving force for the desorption process. In this study, the fly ash zeolite (FAZ) – CO_2 contact system is investigated in dynamic conditions regarding to the establishment of an optimal desorption temperature.

2. Experimental

The solid adsorbent used is FAZ of Na-X type obtained by alkaline activation of Class F fly ash. The FAZ has a specific surface area of 398 m^2/g and an equilibrium CO_2 adsorption capacity of 136.40 mg/g (Zgureva). Dynamic adsorption and desorption studies in the FAZ–CO_2 system were carried out in a specially equipped laboratory set-up presented in Figure 1. The FAZ was exposed in gas mixture streams of N_2 and CO_2 in volumetric ratios of 90/10 (Series 1) and 85/15 (Series 2). The two working gases pass through flow meters to a glas gas mixing valve from where the gas mixture stream is passed through the investigated sample at maintained flow rates (W, ml/min). The gas mixture is thermostated at 24 ^oC by passing through a heated gas line, and continues to a multi-way valve from where it is directed to a glass adsorption column. The laboratory column is filled with 1.2 g FAZ with an adsorbent layer height ca. 2 cm. A quartz filter with a particle size of 1.25 mm is installed in order to prevent the transfer of the powdered sample into the stream. By gas chromatograph HP-GC with 25 m PLOT Q capillary column and carrier gas N_2, was built breakthrough curves of CO_2 concentration in the exhaust stream. Four runs were performed for both experimental series to determine the optimal temperature of desorption. The investigated temperature range of CO_2 desorption is 50-200 ^oC.

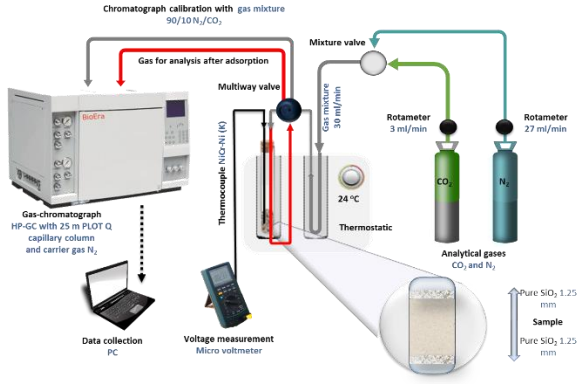

Figure 1. Experimental set-up for dynamic adsorption/desorption studies.

3. Results and Discussions

The obtained breakthrough curves for both experimental series are plotted in Figures 2 and 3.

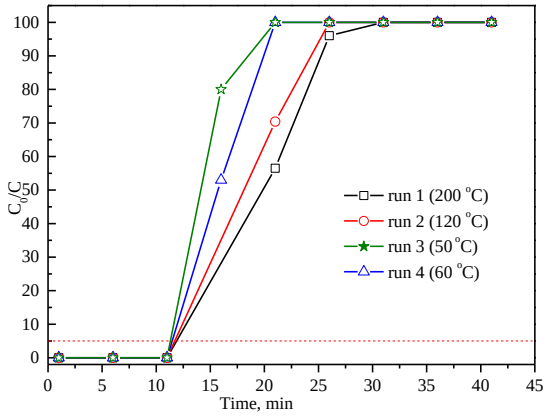

Figure 2. Breakthrough curves for Series 1.

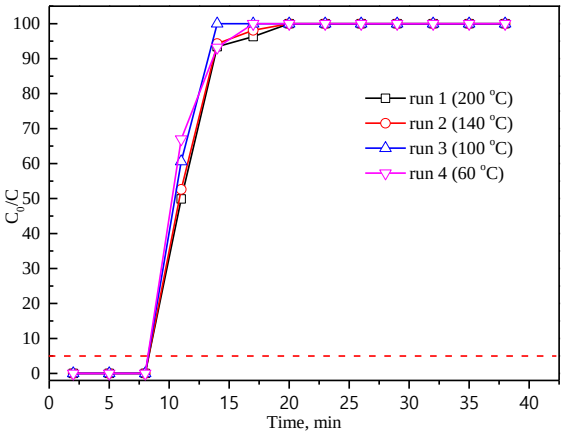

Figure 3. Breakthrough curves for Series 2.

The mass transfer in the adsorption column is more intensive for all runs in Series 2 because of the higher CO_2 concentration in the gas mixture. In both cases, the breakthrough point at CO_2 concentration of 5 vol % in the exhaust gas is established at approximately the same time for all runs performed after thermal desorption. In a case of an industrial installation, the adsorption column should be switched to the desorption mode at this concentration of the exhaust gas. The dynamic parameters of the FAZ-CO_2 system are given in Table 1.

Table 1. Dynamic adsorption/desorption parameters of FAZ-CO_2 system

N_2/CO_2 volumetric ratio of 90/10					
	T, °C	200	120	50	60
Series 1	τ_1, min	11.9	11.7	11.3	11.5
	τ_2, min	31.0	26.0	21.0	21.0
	C_{ads}, mgCO_2/g FAZ	115	108	100	100
N_2/CO_2 volumetric ratio of 85/15					
	T, °C	200	140	100	60
Series 2	τ_1, min	8.0	8.0	8.0	8.0
	τ_2, min	20.0	20.0	15.0	17.0
	C_{ads}, mgCO_2/g FAZ	99	97	92	92

T – temperature of desorption
τ_1– time for release of 5 vol % CO_2 in exhaust gas
τ_2– time for release of 100 vol % CO_2 in exhaust gas
C_{ads} – adsorption capacity

4. Conclusion

Due to the high CO_2 dynamic adsorption capacity of FAZ and the small deviation in the breakthrough times at 5 vol % CO_2 in the exhaust stream varying the regeneration temperatures, it was found that the desorption process could be realized effectively at temperatures of 50 °C. This low desorption temperature is an advantage of the proposed technology from the technical and economical point of view, as compared to the high energy demands for thermal recovery of aqueous solutions of amino derivatives used for CO_2 chemisorption.

Acknowledgements

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