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Short Communication

Effect of Desorption Pressure on CO_2 Separation from Combustion Gas by Means of Zeolite 13X and Activated Carbon

Dariusz Wawrzyńczak*, Dominika Bukalak, Izabela Majchrzak-Kucęba, Wojciech Nowak

Institute of Advanced Energy Technologies, Faculty of Environmental Protection and Biotechnology, Częstochowa University of Technology, Dąbrowskiego 73, 42-201 Częstochowa, Poland

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Abstract

This paper discusses the effects of desorption pressure on CO_2 separation from a simulated mixture of flue gas coming from the process of conventional coal combustion in a power plant by means of the vacuum-pressure swing adsorption (V-PSA) technique. The process was carried out in a two-bed installation filled with two granulated adsorbents: (1) zeolite 13X and (2) activated carbon (AC). The effects of feed flow rate and time of the adsorption step also were evaluated. The results obtained in the study suggest a substantial effect of the parameters analyzed on CO_2 content in the enriched product, and on the recovery from feed gas.

Keywords: CO_2 separation, adsorption, V-PSA, zeolite 13X, activated carbon

Introduction

The power industry is one of the largest emitters of carbon dioxide into the atmosphere. Therefore, much effort is being made to reduce CO_2 emissions, not only by increasing the efficiency of production and energy transmission but also by investigating the opportunities to effectively capture and dispose of this gas (storage, industrial applications).

According to the World Energy Outlook 2010 [1], the most effective method of reducing CO_2 emissions into the atmosphere is its capture. This is possible through construction of carbon processing units (CPUs) next to the already existing power plants that burn fossil fuels and remove CO_2 in the post-combustion capture process. The CPUs do not disturb production of electricity as they are separate units that are supposed to process the combustion gas and consume only a part of the energy generated. A great deal of research has been done in order to improve the process through determination of the most effective parameters related to the operating costs of the system.

Due to its universality, particular attention among many methods of carbon dioxide separation from combustion gases (absorption, adsorption, membrane, and cryogenic methods) has been paid to the adsorption method that is widely used in air separation [2, 3], recovery, and purification of hydrogen [3], and methane from landfill biogas [3, 4] and air drying [3]. The studies have been carried out in the field of its application in carbon dioxide separation from conventional combustion gases [5-8], gases from oxygen-enriched combustion [9], or even in cooling systems [10]. In the case of carbon dioxide separation from flue gases coming from the conventional combustion process, the vacuum-pressure swing adsorption (V-PSA) technique deserves particular attention. The technique does not necessitate excessive compression of feed gas while the energy is input for evacuation of the product (CO_2-enriched gas) [6].

*e-mail: dwawrzynczak@is.pcz.czest.pl

A number of scientific papers have discussed the V-PSA technology in carbon dioxide separation from combustion gases. Most of the studies have been carried out at low desorption pressures of up to 100 mbar [5-8]. Some of them focused on laboratory experiments [6, 7] while others preferred numerical simulations [5, 8].

The paper presents effects of desorption pressure, feed flow rate, and time of the adsorption step, and shows the effectiveness of the V-PSA process performed in the same installation for the two adsorbents: zeolite 13X and activated carbon. Furthermore, the pressure of 200 mbar was used for the desorption step for comparison purposes (i.e. different than 30 and 100 mbar).

Experimental Procedures

The investigations of carbon dioxide separation from a simulated mixture of combustion gas were conducted in a two-bed installation using a vacuum-pressure swing adsorption technique (Fig. 1). It was assumed that the feed gas stream is dry and contains 16% CO_2, 3.5% O_2, and 80.5% N_2. The flow rate of the feed gas and low-pressure (CO_2 enriched product) and high-pressure (CO_2 lean product) products was measured by flow mass meters and adjusted by solenoid and manual metering valves. The carbon dioxide concentration was measured by NDIR sensors.

The granulated adsorbents used in the process were: zeolite 13X (diameter av. 5.0 mm, bulk density of 560 kg/m^3, BET 466 m^2/g) and coconut shell steam-activated carbon (mesh 4×8, bulk density of 385 kg/m^3, BET 1,035 m^2/g).

The cycle for one bed includes four steps. In the first step (adsorption), feed gas enters the bottom of the bed and exits to the atmosphere through the top of the bed. The second step is pressure equalization between the two beds. The third step (desorption) is countercurrent evacuation of the adsorptive carbon dioxide (and co-adsorbed N_2, O_2) under vacuum. Repressurization of the bed with feed gas finishes the whole cycle.

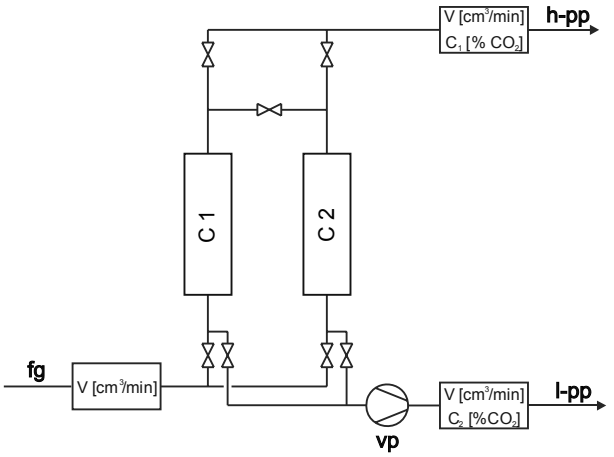

Fig. 1. Schematic diagram and details of V-PSA installation. C1, C2 – reaction column, vp – vacuum pump, fg – feed gas, h-pp – high-pressure product, l-pp – low-pressure product.

A range of six different times of adsorption (300 s, 600 s, 900 s, 1,200 s, 1,500 s, 1,800 s), three evacuation pressures (30 mbar, 100 mbar, 200 mbar), and two feed flow rates (90 cm^3/min, 150 cm^3/min) were used to estimate the effect of the process parameters on carbon dioxide purity in the product and CO_2 recovery from the feed gas. Feed pressure of 125 kPa abs. was used to minimize flue gas compression. The desorption time was generally set as half time of the adsorption time in most investigations. To obtain stable conditions the temperature of the column was maintained at ca. 30ºC.

Results

The separation process was carried out until cyclic steady state was observed. The calculations of average carbon dioxide concentrations in low-pressure product (C_{prod}) as well as average recovery of CO_2 from feed gas (R_{eco}) were performed for one cycle of the process. These results were presented as a function of adsorption time and as a dependence on the desorption pressure and feed flow rates in Figs. 2-5.

Discussion of Results

Carbon dioxide concentrations observed for 13X zeolite were from ca. 8% up to 20% higher compared to the results obtained for activated carbon depending on the set parameters. On the contrary, CO_2 recovery from feed gas for the shortest time of adsorption and the lowest desorption pressure did not differ significantly, but for other parameters it was greater by up to 20% for AC vs. zeolite 13X. Reduction in the desorption pressure yielded higher concentrations of carbon dioxide and CO_2 recovery. In general, higher adsorption times and feed flow rates allowed for higher CO_2 concentrations but lower CO_2 recovery. This is related to the bed's load with adsorbate. A part of the bed

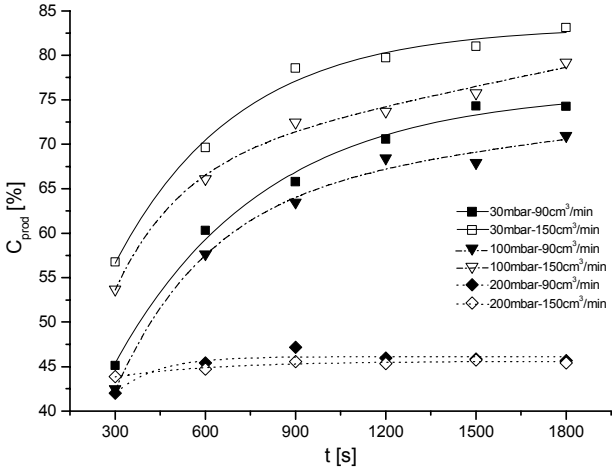

Fig. 2. The effect of adsorption time, desorption pressure and feed flow rate on CO_2 concentration in low-pressure product (zeolite 13X).

was unloaded due to the short time of adsorption step, which yielded (at the desorption pressure of 30 mbar) a lower concentration of CO_2 in the product but higher recovery of CO_2 in comparison with the pressure of 100 mbar. This situation was observed only for activated carbon due to its high kinetics. An excessively long adsorption time, equal to or longer than 600 s for desorption pressure of 200 mbar, failed to produce any effect on CO_2 concentrations in the low-pressure product and was the case for lower recovery.

Conclusions

The study demonstrated a substantial effect of desorption pressure on carbon dioxide recovery from feed gas and on CO_2 purity. Furthermore, other parameters, such as time of desorption step and feed flow rate (which determine the load of the bed) were closely related. Therefore, it is important to choose the appropriate process parameters and the type of sorbent. The higher CO_2 concentrations in the product and recovery from the feed gas might be achieved by means of introducing more steps, e.g. purge step, gas recirculation process, or even introducing an additional enriched stage of V-PSA separation.

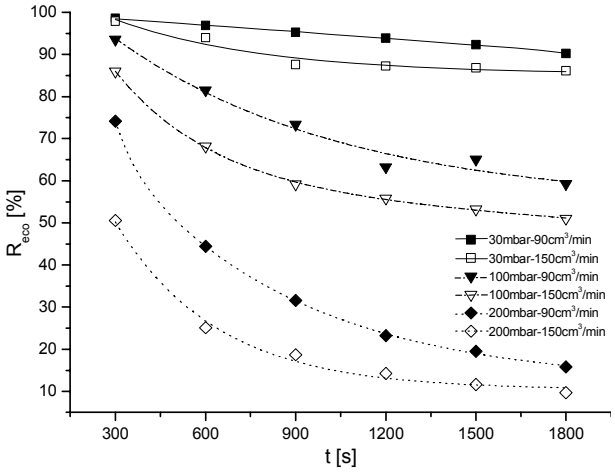

Fig. 3. The effects of adsorption time, desorption pressure, and feed flow rate on CO_2 recovery (zeolite 13X).

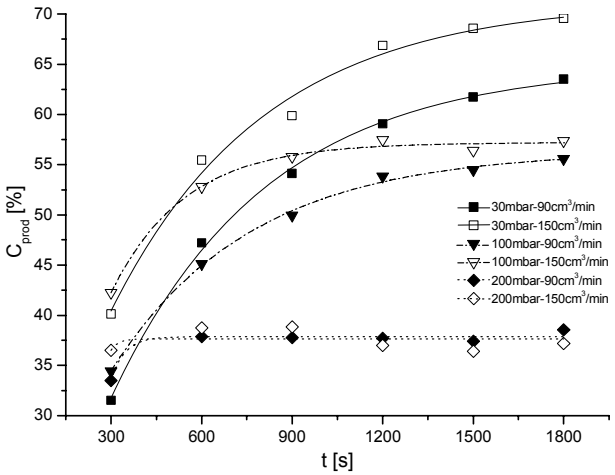

Fig. 4. The effects of adsorption time, desorption pressure, and feed flow rate on CO_2 concentration in low-pressure product (AC).

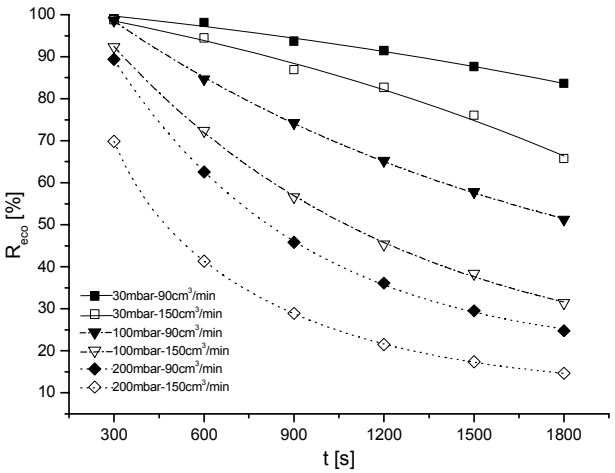

Fig. 5. The effects of adsorption time, desorption pressure, and feed flow rate on CO_2 recovery (AC).

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