

Use of phase change materials on an adsorbed carbon dioxide storage system



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HIGHLIGHTS

- ▶ A tank filled with granulated activated carbon.
- ▶ Phase change materials (PCM) as heat exchanger.
- ▶ Adsorption and desorption temperatures, and CO₂ discharge amount.
- ▶ Numerical simulation of the process.
- ▶ Amount of desorbed CO₂ using PCM spheres on carbon bed.

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ABSTRACT

This paper studies the thermal effect resulting from the adsorption of carbon dioxide (CO₂) on both charge and discharge on an adsorbed storage system using phase change materials (PCM) as heat exchanger. A 0.16 m³ tank filled with granulated activated carbon was used, where 360 PCM spheres (40 mm diameter) were placed inside. Adsorption and desorption temperatures, together with CO₂ discharge amount were recorded experimentally from 0.8 to 3.0 MPa adsorption pressure. Results shown that experimental temperature profiles are well contrasted with numerical simulation of the process obtained using STAR CCM+ software. It was observed that it is possible to mitigate temperature fluctuation, rising adsorption and decreasing desorption, as well as increase the amount of desorbed CO₂, with the use of PCM spheres. The best discharged amount of desorbed CO₂ was 8952 L at 3.0 MPa using PCM spheres on carbon bed.

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1. Introduction

Carbon dioxide is a naturally occurring greenhouse gas in the atmosphere. Nevertheless, its concentrations have increased as a result of human activity, such as burning of coal, oil, natural gas and organic matter. Today, world's fossil fuel consumption (expressed as gigatons of carbon) is 6 (GtC/year), this consumption produces nearly 22 gigatons of CO₂ per year, implicating that rising atmospheric CO₂ concentration is one of the major environmental problems because of its implication in global warming. That's why there has been a worldwide effort to reduce CO₂ emissions in order to mitigate their adverse effects on the planet. Joint to the efforts to minimize the use of fossil fuels, two major strategies can be considered in order to avoid the entrance of CO₂ to the atmosphere. The first strategy is the capture and geological storage of carbon dioxide and the second strategy is the CO₂ activation and their efficient transformation in another valuable chemical products.

CO₂ capture and storage (CCS) offers great potential. It is estimated that, in several scenarios, CO₂ captured using CCS is going to represent between 15% and 55% of greenhouse gases reduction by the year 2100 [1]. Among the tests proposed by the EEUU pilot, it is planned to implement small installations where CO₂ will be captured in energy production plants and placed for long-term storage in earth crust avoiding CO₂ emission to the atmosphere. However pressure accumulation in the subsoil induced by CO₂ injection from industrial-scale projects is a key limitation for the amount of CO₂ that can be safely stored in the subsurface [2]. According to Hansson [1], CCS problem is that it is still a relatively untested method, therefore, the biggest challenge is to find the best way to demonstrate that CO₂ capture and storage is safe, effective and can be performed at industrial scale at competitive costs. Given the problems mentioned, CO₂ capture on adsorbents followed by their controlled releasing for utilization and catalytic transformation could be transformed in a potentially interesting new technology.

Several solids adsorbents have been shown to be suitable for capturing CO₂ from gas phase, many materials with important porous structures like silicates, silica, alumina, silica–alumina,

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zeolites, activated carbons, other carbon based materials, metal-organic frameworks (MOFs), composites resins, and membranes can be mentioned [3–8]. Other solids like carbon molecular sieve-based material functionalized with amine groups, amine surface-bonded silica gel [9], acrylic ester resin-based solid amine adsorbent and hydrotalcites [10,11], have been proven for CO₂ storage. The existence of pores or cavities in certain types of solids implicate high specific surface, or a great adsorption capacity, so materials such as zeolites can have values between 600 and 700 (m²/g) and activated carbon can have values of more than 1000 (m²/g).

There are several publications on the issue of CO₂ adsorption on adsorbent materials; however, those experiments have been made adsorbing CO₂ mixed with other gases [12], as well as using low adsorption pressures and zeolite as adsorbent material [13–15]. Moreover, these publications do not emphasize in the measurement of the thermal behavior of the activated carbon inside the tank to the process of adsorption and desorption.

The physical adsorption process is basically a process related with Van der Waals forces in which gas molecules strike the solid surface of the adsorbent and fixed it in a non-dissociative way [16]. The existence of mathematical equations of adsorption isotherms, such as Freundlich, Langmuir, Brunauer–Emmet–Teller are tools used for estimate the behavior of the adsorbed amount of gas in a solid to a specific gas pressure and constant temperature [17–19]. Considering that the adsorption is an exothermic process, this energy release brings the undesirable effect of decreasing the adsorption capacity of adsorbent. From this point of view in some experiments with diverse gases have been implemented heat exchange systems, which have consisted the use of straight and U-tubes [20–22], use of corrugated plates inside [23], grids pipes connected by wings [24], copper bars filled with salt hydrate and phase change materials [25]. The last alternative [25] offers a variety of options in terms of their properties, also are materials capable of storing high amounts of energy.

The objective of this paper is to study the thermal effect resulting from adsorption heat both in the charge and discharge of carbon dioxide (CO₂) on an absorbed storage system using PCM as heat exchanger. The thermal effect in 0.16 m³ of storage tank is evaluated at adsorption pressures from 0.8 to 3.0 MPa on commercial activated carbon, and the CO₂ volume desorbed is measured.

2. Experimental apparatus and procedure

The experimental apparatus consists of three main sections: CO₂ transport system, storage vessels and data logger [26]. The CO₂

transport system has four lines of pressure, temperature and flow meters: (1) adsorption line transports gas from CO₂ cylinder (5.6 MPa) to the adsorption tank reducing pressure through a regulator, (2) exit line connected the tank with desorption line, (3) vacuum line, and (4) desorption line transports CO₂ from exit line to the atmosphere reducing pressure through a regulator. In desorption line the gas flow is measured with an Aalborg flow meter. Finally, the vacuum line removed excess gas from the tank to the atmosphere. All lines are capable of withstanding pressures up to 20 MPa. For details see Ref. [26].

A horizontal storage tank of 164.5 L and activated carbon Norit G1220 Extra were used as adsorbent bed. To verify the properties of the adsorbent, tests were performed at N₂ base at a temperature of 77 K in the Department of Physics–Chemistry of the University of Concepcion, Chile. This procedure is the most used to characterize an active carbon and is known as the Brunauer–Emmet–Teller (BET) method [17,18], which is based in the physical adsorption of a gas on a solid surface, in which 77 K is the boiling point at atmospheric pressure of N₂. Tests were conducted in a range of pressure below 1 atm. Obtained data are the volumes of adsorbed gas on a series of pressure in the adsorption chamber. The properties results are BET surface area of 1496 m²/g and pores size of 1.76240 nm.

For the adsorption process, the pressure regulator on the adsorption line is placed at the required pressure and CO₂ enters to the tank until pressure stabilizes. For flow measurement in desorption process, the pressure regulator on desorption line is placed at 0.1 MPa and the process ends when the flow is minimal. Temperature data were collected by J-type thermocouples, consisting in nine thermocouples placed in the horizontal tank (Fig. 1). Voltage signals from these thermocouples were transferred to a computer, where they were digitalized using module Omega OMB-DAQ-55. Before each experiment storage deposit and work line are submitted to vacuum conditions at a pressure of approximate –0.04 MPa to remove residual gases.

PCM spheres were selected like an efficient heat exchange system, according with the needs to mitigate the temperature inside the tank and keep it stable. PCM spheres of organic material packed in rubber, 40 mm in diameter, with a phase change temperature of 22 °C, melting point of 80 °C, specific heat of 2.22 kJ/kg K, thermal conductivity of 0.18 W/mK, latent and sensible heat of 135 MJ/m³ and 102 MJ/m³, respectively, were used. Three hundred and sixty spheres were used inside the tank with an equivalent volume of 13.6 L and total mass of 3.7 kg. Positioning of the PCM spheres were performed covering most of the tank and

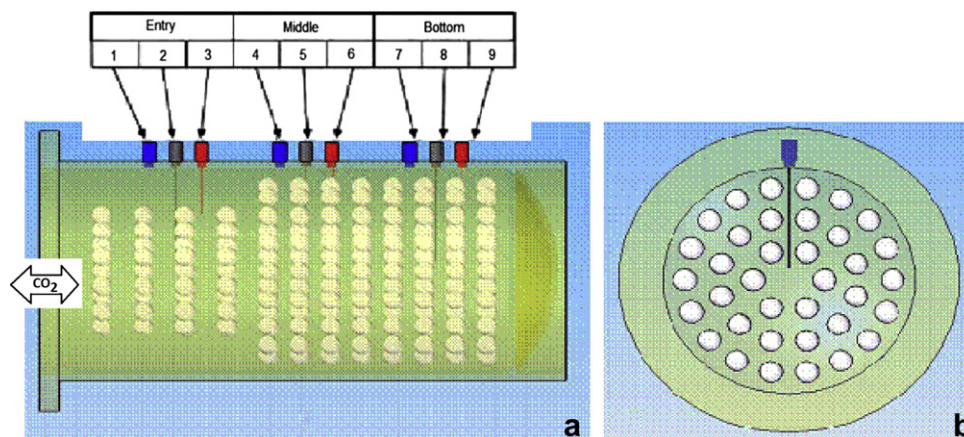


Fig. 1. Tank with PCM spheres and nine thermocouples in view (a) lateral and (b) front. The thermocouples number 1, 4 and 7 were located at 1 cm deep; 2, 5 and 8 at 20 cm deep; and 3, 6 and 9 at 10 cm deep. The thermocouples are between spheres (without contact).

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