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Short Communication

CO₂ desorption via microwave heating for post-combustion carbon capture

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ABSTRACT

In this work, a comparison of CO₂ desorption rates of microporous activated carbon (AC) using Microwave Swing Desorption (MSD) and Temperature Swing Desorption (TSD) is reported. For the purposes of this study, a modified microwave oven and a conventional oven were used, heating the AC packed bed to two different temperatures (70 °C and 130 °C). Results showed that microwaves are able to enhance the rate of CO₂ desorption from the AC, contributing to a four times faster overall desorption process, compared to conventional heating desorption.

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1. Introduction

In recent years, there has been an increasing global interest in carbon dioxide capture and storage (CCS), mostly due to the fact that coal is still the dominant feedstock for energy production [1]. In post-combustion capture technology, CO₂ is separated from a diluted flue gas stream that contains typically around 12–15% CO₂, at ambient pressure and at temperatures of 40–100 °C [2]. This capture process represents about 70% of the total cost of CCS, and therefore, adsorption technology that can offer high operating flexibility and low maintenance costs, is gaining support compared to conventional absorption using alkanolamines [3]. Efficient regeneration systems ensuring multiple use of adsorbent materials, while consuming the least possible energy, are required. In this study, the effect of microwave heating for adsorbent regeneration is investigated.

Microwave Swing Desorption (MSD) offers possible advantages over Temperature Swing Desorption (TSD), due to faster heating rates, leading to a more rapid desorption process, while consuming less energy [4]. Moreover, there has also been some evidence that microwave irradiation may be responsible for better performance

of the sorbent in terms of adsorption rates and capacity compared to conventional heating, resulting in more regeneration cycles whilst maintaining the sorbent's textural properties [5]. Nevertheless, the concept of MSD for CO₂ capture using adsorbents is quite new and has not been studied before. Accordingly, the aim of this paper is to compare the desorption rates of MSD and TSD.

In this work, experimental studies of fixed bed CO₂ adsorption on microporous granular activated carbon (AC) with regeneration via MSD and TSD has been evaluated.

2. Experimental section

2.1. Material

A commercial AC provided by NORIT (product name: NORIT GCN 3070) was used. This particular AC has been produced from coconut shell by using steam physical activation. The particle size of the AC measured by the supplier was 210–595 μm (30–70 mesh, 93%), the surface area was 1514 m²/g, while the pore diameter was 1.2 nm.

2.2. Lab-scale experimental setup

Fig. 1 shows a schematic representation of the lab-scale experimental setup used. The setup includes a fixed-packed bed column (length = 250 mm, outside diameter = 30 mm, inner

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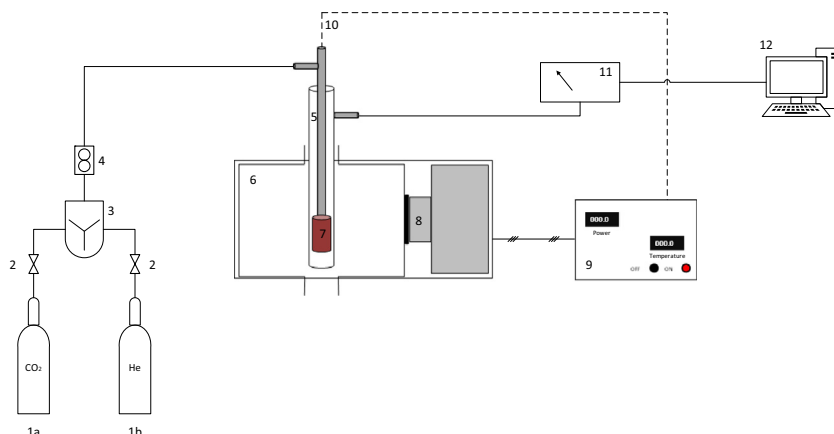


Fig. 1. Layout of the experimental rig, (1a) Gas cylinder – CO₂, (1b) Gas cylinder – He, (2) Valve, (3) Gas mixer, (4) Mass flow controller, (5) Reactor column, (6) Microwave cavity, (7) AC packed bed, (8) Magnetron, (9) PID temperature controller, (10) IR Pyrometer, (11) Mass Spectrometer (MS), (12) PC.

diameter = 10 mm, AC packed bed diameter = 20 mm) fabricated from Pyrex glass, equipped with a grade 1 (90–150 μm) sintered disk. A gas mixture containing 50% CO₂ and 50% He was produced using a Quantachrome gas mixer generating a constant total flow of 40 ml/min.

The fixed-bed temperature was determined by an InfraRed (IR) pyrometer (Optris CTfast CT LT 25F) which measured the AC bed temperature from the top of the reactor through a zinc selenide (ZnSe) window. The IR pyrometer was also connected to a PID controller (Eurotherm 3504) during microwave heating, which was able to control the power needed to reach the specific target temperature. Experiments for examination of the conventional heating desorption were conducted using a commercial tubular furnace also provided by Quantachrome.

CO₂ and He concentrations were continuously measured by a mass spectrometer provided by Hiden analytical (HPR-20 QIC) and the data were acquired and analysed using Hiden QGA Pro software.

2.3. Evaluation method of CO₂ desorption in the activated carbon bed

For all experiments, 5 g of AC were placed inside the fixed bed, purged with 20 ml/min flow of He for one hour and then loaded with a 40 ml/min He/CO₂ (50:50) gas stream at room temperature and atmospheric pressure. Desorption experiments were also carried out with the same 40 ml/min He/CO₂ (50:50) gas stream.

For easier comparison of the experimental data, the expression *reverse breakthrough time* (t_{90}) was defined as the time needed to achieve 90% desorption after reaching the desired temperature. The amount desorbed (Q_{des}) was calculated by Eq. (1):

$$Q_{des} = \int_0^{t_{90}} Q(t) dt \quad (1)$$

Moreover, t_h refers to the time needed for the bed to reach the specific temperature, t_{50} corresponds to the time needed to desorb 50% of the total desorbed amount, t_{tot} is the total time of the desorption process ($t_h + t_{90}$) while dQ/dt_{av} describes the average desorption rate during each process.

3. Results and discussion

Figs. 2 and 3 represent the time-dependent CO₂ outlet concentration profiles during CO₂ desorption by conventional heating (CH) and by microwave heating (MW) using two different temperatures, 70 °C and 130 °C. It can be observed that there are

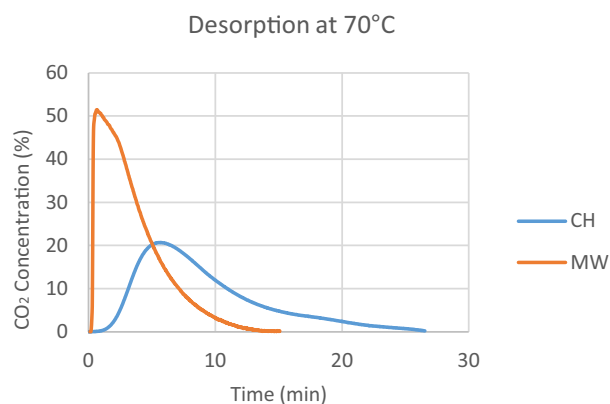


Fig. 2. Comparison between microwave and conventional heating desorption at 70 °C.

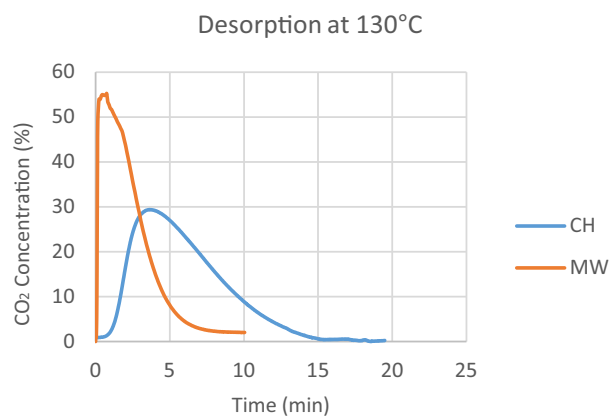


Fig. 3. Comparison between microwave and conventional heating desorption at 130 °C.

two different outlet concentration patterns, both of which follow the log-normal distribution. This distribution suggests that the maximum CO₂ outlet concentration is reached relatively fast, meaning that most of the adsorbed CO₂ is quickly desorbed, due to the rapid diffusion of the gas in the fine porous structure of the AC [3].

Table 1
Main parameters obtained from AC regeneration experiments under conventional and microwave heating – CH₇₀: conventional heating at 70 °C, MW₇₀: microwave heating at 70 °C, CH₁₃₀: conventional heating at 130 °C, MW₁₃₀: microwave heating at 130 °C, t_h : time needed for the AC bed to reach the desired temperature, Q_{des} : amount desorbed, t_{50} : time needed for 50% of Q_{des} , t_{90} : reverse breakthrough time, dq/dt_{av} : average desorption rate, $t_{tot} = t_h + t_{90}$.

	t_h (min)	Q_{des} (ml)	t_{50} (min)	t_{90} (min)	dq/dt_{av} (ml/min)	t_{tot} (min)
CH ₇₀	6	25.65	8	16.5	1.54	22.5
MW ₇₀	1.5	31.85	2.5	7	4.61	8.5
CH ₁₃₀	15	26.92	5.5	10	2.66	25
MW ₁₃₀	5.5	24.48	1.5	4.5	5.09	10

One interesting difference to note is that the maximum desorption (curve peaks) and the duration of the process are different for both temperatures, depending on the desorption method followed; in the case of MW the peak is reached clearly faster, approaching ~55% of CO₂ in less than 30 s. On the other hand, in the case of CH, the peak only reaches 20% (and 30% when desorbing at 130 °C) of CO₂ after 2 min of heating the bed at 70 °C. In addition, the CO₂ desorption process of the MW does not exceed 7 min at 70 °C (5 min for 130 °C) whereas the inverse breakthrough time for both temperatures during the CH process is ~2.5 times longer. Another apparent difference between the two patterns is the long tail that can be observed in the CH process; this tail suggests that the residual CO₂ desorption takes place slowly while, in the case of MW, the curve reaches an asymptote more rapidly, indicating that almost all the CO₂ abandons the AC immediately after irradiating the AC bed with electromagnetic energy.

Table 1 lists the most important calculated values for the comparison of CH and MW. It can be observed that the desorption rate at both 70 °C and 130 °C was much higher when using MW compared to CH, mainly due to the fact that these two heating systems generate heat differently; when heating with MW, energy transfer does not happen initially by conduction and convection like in CH, but is readily transformed into heat inside the particles by either dipole rotation or the Maxwell–Wagner polarisation [6], which is the case for the AC (complex permittivity: $\epsilon' = 15$ and $\epsilon'' = 5.5$ at 2.45 GHz and 23 °C [7]). Moreover, it is clear that t_h is significantly lower when heating with MW, which has also a positive effect on the t_{tot} resulting in the overall desorption process being ~2.5 times faster when using MW compared to CH technology.

Finally, the differences in the desorption parameters between the conventional and microwave heating are always higher at 70 °C than at 130 °C. These results are in agreement with those previously reported for pyrolysis processes [8], suggesting that MW heating is more efficient than CH at lower temperatures.

4. Conclusions

In this work, a microporous granular activated carbon (AC) was used to study CO₂ desorption via microwave and conventional heating. Two particular temperatures were investigated (70 °C and 130 °C). Experimental results showed that even though both heating processes follow the log-normal distribution, there is a clear distinction between them; microwave heating results in faster CO₂ desorption rates, without the drawback of a slow desorption of the residual CO₂, compared to conventional heating. Moreover, according to the aforementioned data, it is possible to heat the AC bed 3–4 times faster when using MW. As a result, MW offers the possibility of a more accelerated overall CO₂ desorption process when using AC as adsorbent by increasing desorption rates significantly.

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