

Sustainable porous carbons with a superior performance for CO₂ capture

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Abstract

Sustainable porous carbons have been prepared by chemical activation of hydrothermally carbonized polysaccharides (starch and cellulose) and biomass (sawdust). These materials were investigated as sorbents for CO₂ capture. The activation process was carried out under severe (KOH/precursor=4) or mild (KOH/precursor=2) activation conditions at different temperatures in the 600-800°C range. Textural characterization of the porous carbons showed that the samples obtained under mild activating conditions exhibit smaller surface areas and pore sizes than those prepared by employing a greater amount of KOH. However, the mildly activated carbons exhibit a good capacity to store CO₂, which is mainly due to the presence of a large number of narrow micropores (< 1 nm). A very high CO₂ uptake of 4.8 mmol·g⁻¹ (212 mg CO₂·g⁻¹) was registered at room temperature (25°C) for a carbon activated at 600°C using KOH/precursor=2. To the best of our knowledge, this result constitutes the largest ever recorded CO₂ uptake at room temperature for any activated carbon. Furthermore, we observed that these porous carbons have fast CO₂ adsorption rates, a good selectivity for CO₂-N₂ separation and they can be easily regenerated.

Broader context

The mitigation of carbon dioxide emissions is attracting widespread attention due to the fact that this gas is the main anthropogenic contributor to climate change. Among the possible strategies for CO₂ abatement, that of capture and storage has attracted keen interest. In this regard, the use of solid sorbents to capture CO₂ by means of pressure, temperature or vacuum swing adsorption systems constitutes a promising alternative. To accomplish this objective the sorbents need to satisfy important conditions: i) low-cost and high availability, ii) a large CO₂ uptake, iii) a high sorption rate, iv) a good selectivity between CO₂ and other competing gases (i. e. N₂) and v) an easy regenerability. However, the development of a solid sorbent that satisfies all these conditions has so far proved to be complex. Here we present a novel route for the preparation of carbon-based porous sorbents of CO₂ from a low-cost sustainable biomass product (sawdust). The results obtained show that these carbon sorbents exhibit very large CO₂ adsorption uptakes of up to 4.8 mmol·g⁻¹ (212 mg CO₂·g⁻¹) at room temperature (25°C), a value that far exceeds those reported in the literature for activated carbons. Furthermore, these carbon sorbents exhibit high sorption rates, a good CO₂-N₂ selectivity and they can be easily regenerated.

Introduction

The control of anthropogenic CO₂ emissions is a crucial matter in view of the significant role that this gas plays in global climate change. In recent years, great efforts have been directed towards the development of new technologies for CO₂ capture and its storage, the improvement of energy efficiency and the generation of energy from non-fuel sources. For the capture of CO₂, the most popular technology is the absorption process using alkanolamine solvents.¹ However, this process presents several disadvantages, such as a high energy consumption, solvent regeneration, the corrosion of the equipment and toxicity.² A promising alternative technology to the liquid-phase absorption process is to use porous solids as sorbents for capturing CO₂ by means of pressure, temperature or vacuum swing adsorption systems.³⁻⁸ To this end, numerous porous solids including zeolites, metal-organic frameworks (MOFs), porous carbons or organic-inorganic hybrid sorbents have been investigated.⁹⁻¹¹ Hybrid sorbents require costly and multi-step fabrication procedures that involve the impregnation or grafting of porous solids (i. e. silica or carbons) with different types of amines.¹²⁻¹⁶ Furthermore, these materials require high regeneration temperatures and undergo a substantial loss of adsorption capacity after several cycles. Of the sorbents mentioned so far, porous carbons have several important advantages in terms of cost, availability, large surface area, an easy-to-design pore structure, hydrophobicity and low energy requirements for regeneration. However, most activated carbons exhibit CO₂ uptakes below ~ 3-4 mmol CO₂·g⁻¹ sorbent (25°C, 1 atm), the value reported as representing the minimum working capacity necessary to compete with the liquid-phase amine systems.¹⁷ In order to improve the CO₂-adsorption capacity of porous carbons, a large amount of research effort has been directed towards the creation of superficial basic sites *via* the incorporation of nitrogen groups into the carbon framework.¹⁸⁻²⁰ However, until now this strategy has only produced moderate enhancements of CO₂ uptakes. Thus, Hao et al. recently reported a maximum CO₂ adsorption capacity of 3.13 mmol·g⁻¹ (25°C, 1 atm) for N-enriched carbon

samples (N content up to 1.9 wt %).²⁰ Wahby et al. showed that carbons with high surface areas produced by the chemical activation of petroleum pitch exhibit an excellent performance for CO₂ adsorption (4.7 mmol·g⁻¹ at 25°C and 1 atm).²¹ This result clearly demonstrates that porous carbons with a suitable pore structure are excellent sorbents for CO₂ capture.

Taking into account the potential scale involved in the production of porous carbons for CO₂ capture, the use of renewable sources for fabricating these materials would seem highly desirable. This could be achieved by employing biomass or biomass-derived products as precursors for the production of carbon sorbents for CO₂ capture. Unfortunately, to date this alternative has hardly been explored to this end. In this paper we present a novel route for the preparation of carbon-based CO₂ sorbents from sustainable biomass products. The results obtained show that these carbon materials exhibit large CO₂ adsorption uptakes, which are far superior to those reported in the literature for activated carbons. The present work focuses above all on the relationship between the porous characteristics of the carbon sorbents and their capacity for CO₂ adsorption. Interestingly, the porosity of these carbons can be easily designed by simply modifying the operational conditions (i. e. activation temperature and the amount of activating agent). It is worth mentioning that, if the pore characteristics of these carbons are properly designed, their capacity for CO₂ adsorption can be optimized and fully exploited.

Experimental

Synthesis of porous carbons

Carbonaceous materials were prepared by hydrothermal carbonization of the following substances: potato starch (Sigma-Aldrich), cellulose (Aldrich) and eucalyptus sawdust. Briefly, an aqueous dispersion of the raw material (concentration: 320 g L⁻¹) was placed in a stainless steel autoclave, heated up to 250°C and maintained at this temperature for 2 h. The

resulting carbonaceous solid, denoted as hydrochar (HC), was recovered by filtration, washed with distilled water and dried.

The hydrochar materials were chemically activated using potassium hydroxide (Sigma-Aldrich). Briefly, a HC sample was thoroughly mixed with KOH at the desired weight ratio (KOH/HC=2 or 4), after which the mixture was heat treated up to the target temperature (heating rate: $3^{\circ}\text{C min}^{-1}$) under a nitrogen gas flow and held at this temperature for 1 h. The samples were then thoroughly washed several times with 10 wt % HCl to remove any inorganic salts, washed with distilled water until neutral pH and finally dried in an oven at 120°C for 3 h. The activated carbons thus synthesized were denoted as AX-x-z, where X refers to the raw material (A: starch, C: cellulose and S: sawdust), y the KOH/HC weight ratio and z the activation temperature (in $^{\circ}\text{C}$).

Characterization of materials

The morphology of the samples was examined by Scanning Electron Microscopy (SEM) using a Zeiss DSM 942 microscope. Transmission electron micrographs (TEM) were taken on a JEOL (JEM-2000 FX) apparatus operating at 200 kV. The nitrogen sorption isotherms and textural properties of the carbons were determined at -196°C using a conventional volumetric technique (Micromeritics ASAP 2020). The surface area was calculated by the BET method from the adsorption data obtained in the relative pressure (p/p_0) range of 0.04 to 0.2. The total pore volume was determined from the amount of nitrogen adsorbed at $p/p_0=0.99$. The pore size distribution (PSD) was calculated *via* a Non Local Density Functional Theory (NLDFIT) method using nitrogen adsorption data and assuming a slit pore model. The micropore surface area and total micropore volume (pore size < 2 nm) were obtained *via* a t-plot analysis. The volume of the narrow micropores (< 0.7 nm) was determined by the applying the Dubinin-Radushkevitch (D-R) equation to the CO_2 adsorption data at 0°C .²²

CO₂ adsorption measurements

The adsorption of CO₂ was measured using a Nova 4200e (Quantachrome) static volumetric analyzer. Prior to the adsorption analysis, the sample (around 50-100 mg) was degassed at 150°C for several hours. The CO₂ adsorption experiments were performed at three temperatures: 0°C, 25°C and 50°C.

The adsorption kinetics of the CO₂ and N₂, and adsorption-desorption cycles were measured in a thermogravimetric analyser (C. I. Electronics). Both sets of experiments were performed at 25 °C and the temperature was controlled by means of a circulating bath (Haake K15). For the kinetic analysis, the sample (~ 10 mg) was degassed under a He stream at 200°C for 1 hour. The gas was then switched from He to CO₂ or N₂ (100 mL·min⁻¹) and the weight variation with time was recorded. In the case of the adsorption-desorption cycles, the sample (~ 30 mg) was degassed under a stream of He at a temperature of 200°C before the cyclic experiments. During the adsorption, the carbon sample was exposed to a stream of pure CO₂ (100 mL·min⁻¹). Once the sample was saturated, the gas was switched from CO₂ to He (100 mL·min⁻¹) and the carbon dioxide was desorbed. This adsorption-desorption cycle was repeated several times.

Results and Discussion

Structural properties of the porous carbons

The hydrochar samples obtained by subjecting the raw materials (starch, cellulose or sawdust) to hydrothermal carbonization have a brown colour consistent with a partially carbonized product. Inspection of this material by means of scanning electron microscopy (SEM) reveals interesting changes in relation to the raw materials. The eucalyptus sawdust shows a cellular structure that is typical of lignocellulosic materials (Figures 1a). On the other hand, starch and cellulose are formed by particles with an irregular morphology (images not

shown). The SEM images of the hydrochar samples reveal the presence of a large fraction of carbonaceous microspheres generated during hydrothermal carbonization due to the decomposition of saccharides (see Figs. 1b, 1c and 1d).^{23, 24} In the case of the sawdust-based hydrochar, these microspheres are mixed with irregular structures derived from the non-saccharide components of wood (i. e. lignin) (Figure 1d). Regardless of the hydrochar precursor, all the activated carbons exhibit a similar morphology that is characterized by irregular shaped particles with large conchoidal cavities and smooth surfaces (Figure 1e). This result shows that a drastic morphological change has occurred during the activation process and that the activated carbons retain no memory of the structure of the parent hydrochar. The TEM image of the activated carbon AS-4-700 evidences that the porosity is made up of randomly oriented uniform micropores (Figure 1f).

The textural properties of the activated carbons were analysed by means of nitrogen physisorption. Figure 2a presents a comparison of the N₂ sorption isotherms and pore size distributions (PSDs) of the activated carbons resulting from the chemical activation (700°C, KOH/HC=4) of the hydrochar samples taken from the starch, cellulose and sawdust. Independently of the nature of the precursor, the sorption isotherms have a similar shape and the PSDs indicate that the porosity of these carbons is made up of micropores with a size of around 1.2 nm. As indicated in Table 1, these porous carbons have comparable BET surface areas in the 2200-2400 m²·g⁻¹ range and pore volumes of ~ 1.1 cm³·g⁻¹. Interestingly, the porous carbon derived from a complex, low-cost and highly available material such as sawdust exhibits a similar pore development to the active carbons obtained from more expensive polysaccharides (cellulose and starch). This result anticipates that the porous carbons derived from sawdust, starch and cellulose will exhibit similar CO₂ adsorption capacities. This hypothesis was confirmed by means of CO₂ adsorption experiments (*vide infra*). Consequently, taking into account these results, the sawdust-based hydrochar was

chosen as starting material as it combines low cost and high availability with good CO₂ capture capacity.

Figure 3 shows the N₂ sorption isotherms and PSDs of the samples prepared at different activation temperatures and for two amounts of KOH, i. e. KOH/HC=4 (Figs. 3a and 3b) and KOH/HC=2 (Figs. 3c and 3d). The textural characteristics of these materials are listed in Table 1. The porous carbons obtained for KOH/HC=4 exhibit BET surface areas >2000 m²·g⁻¹ (up to 2850 m²·g⁻¹ for the AS-4-800) and pore volumes >1 cm³·g⁻¹. More interestingly, the porosity of these activated carbons is made up of pores in the micropore-mesopore range (sizes between 1 nm and 3 nm) as evidenced by the PSDs shown in Figure 3b and Table 1. By contrast, the samples synthesised employing KOH/HC=2 and temperatures in the 600-700°C range, exhibit a moderate degree of activation, as evidenced by the relatively low values obtained for the BET surface areas (~ 1300 m²·g⁻¹) and pore volumes (~ 0.6 cm³·g⁻¹) (see Table 1). Unlike the samples obtained for KOH/HC=4, the porosity of the carbons prepared under milder conditions (KOH/HC=2) is made up of narrower micropores with sizes < 1 nm (maxima ~ 0.8-0.9 nm), as illustrated in Figure 3d and Table 1. At a high activation temperature (800°C and KOH/HC=2), there is an enlargement of the size of the micropore (see Fig. 3d) and the activated carbon AS-2-800 exhibits pore characteristics that are comparable to those of the materials synthesised at KOH/HC=4 (see Table 1).

The narrow microporosity (< 0.7 nm) present in these samples was analyzed by applying the Dubinin-Radushkevitch equation to the CO₂ adsorption data obtained at 0 °C. The pore volume (V_o) corresponding to these micropores is listed in Table 1. It can be seen that for the highly activated carbons (KOH/HC=4), these narrow micropores comprise around 30-40 % of the micropore volume (V_{micro}). In contrast, for the porous carbons obtained under milder conditions (KOH/HC=2 and temperatures in the 600-700°C range), the porosity is mostly made up of narrow micropores (> 80 % of the micropore volume). These results show that

the fraction of narrow microporosity depends heavily on the degree of activation to which the carbons are subjected. We observed that this parameter has an important role in determining the CO₂ adsorption properties of porous carbons.

CO₂ capture capacity

The CO₂ adsorption capacities of porous carbons were investigated at three representative temperatures (0 °C, 25 °C and 50 °C). A comparative analysis of the CO₂ adsorption isotherms (measured at 0°C) between the sustainable porous carbons and the commercial activated carbon (M-30) is presented in Figure 4. It can be seen that the CO₂ capture capacities of the three sustainable carbons are quite substantial and similar (about 5.5-5.8 mmol CO₂·g⁻¹, 243-256 mg CO₂·g⁻¹). This result is coherent with the fact that the pore characteristics of these materials are analogous (see Table 1).

Table 2 summarizes the CO₂ capture capacities of the porous carbons. The highly activated sawdust-based carbons prepared by employing KOH/HC=4 exhibit similar CO₂ uptakes irrespective of the activation temperature. Indeed, the capture capacities at adsorption temperatures of 0 °C and 25 °C are in the 5.2-5.8 mmol CO₂·g⁻¹ (230-256 mg CO₂·g⁻¹) and 2.9-3.5 mmol CO₂·g⁻¹ (128-155 mg CO₂·g⁻¹) ranges respectively. Interestingly, the sawdust-based porous carbons prepared under mild activation conditions (KOH/HC=2) exhibit better CO₂ capture capacities than under KOH/HC=4 (see Table 2). The CO₂ adsorption isotherms of the carbon samples prepared under these activation conditions are shown in Figure 5. These adsorption isotherms show that the porous carbons obtained under mild activation conditions (KOH/HC=2) have very large CO₂ uptakes. Thus, at 0°C they are in the 5.8-6.6 mmol CO₂·g⁻¹ (255-288 mg CO₂·g⁻¹) range (see Table 2). At 25°C, the amount of CO₂ adsorbed clearly diminishes with the activation temperature, from 4.8 mmol CO₂·g⁻¹ (212 mg CO₂·g⁻¹) at 600°C to 3.9 mmol CO₂·g⁻¹ (170 mg CO₂·g⁻¹) at 800°C. As expected for an exothermic process such as CO₂ physisorption, the amount adsorbed decreases with the

increase in adsorption temperature. The isosteric heat of adsorption was calculated by applying the Clausius-Clapeyron equation to the adsorption isotherms (adsorption uptake $\sim 0.7 \text{ mmol CO}_2\cdot\text{g}^{-1}$). The values found for the enthalpy of adsorption of these samples are $\sim 20\pm 2 \text{ kJ}\cdot\text{mol}^{-1}$, which is consistent with the data reported for CO_2 adsorption on porous carbons.²⁵

It should be pointed out that, whereas the porous carbons prepared at $\text{KOH}/\text{HC}=2$ have a considerably poorer pore development than those obtained at $\text{KOH}/\text{HC}=4$ (see Table 1), they exhibit significantly better CO_2 capture capacities (see Table 2). This observation is in agreement with the results shown in Figure 4. A comparison of the pore size distributions of both activated carbon series reveals important differences (see Figure 3 and Table 1). Indeed, as mentioned above, whereas the porosity of the carbons prepared at $\text{KOH}/\text{HC}=2$ is mostly made up of narrow micropores ($< 1 \text{ nm}$) (see Figure 3d), the $\text{KOH}/\text{HC}=4$ samples contain quite a large fraction of wide micropores $> 1 \text{ nm}$ and mesopores $> 2 \text{ nm}$ (see Figure 3b). These results clearly indicate that the amount of CO_2 adsorbed depends heavily on the pore size distribution of the samples. More specifically, they show that the narrow micropores ($< 1 \text{ nm}$) have a greater contribution to CO_2 adsorption than wide micropores and mesopores. This is due to the fact that these narrow micropores have strong adsorption potentials that enhance their filling by the CO_2 molecules. This result shows that the fabrication of efficient CO_2 carbon sorbents requires a precise control of the porosity, which should be made up by micropores $< 1 \text{ nm}$.

It is also worth mentioning that the CO_2 capture capacities of the porous carbon samples reported here, and in particular those obtained for the materials prepared under mild activation conditions ($\text{KOH}/\text{HC}=2$), are among the highest ever reported for porous carbons. This is evidenced by comparing our CO_2 uptake data ($25 \text{ }^\circ\text{C}$ and 1 bar) (see Table 2) with those found in the literature for other porous carbons. The results of the comparison are

summarized in Table 3. Indeed, to the best of our knowledge, the AS-2-600 sample, prepared under mild activation conditions (KOH/HC=2 and 600°C), exhibits the highest CO₂ uptake value ever measured for a porous carbon at room temperature (25°C).

Kinetics of adsorption, (CO₂/N₂) selectivity and sorbent regeneration

For a low-cost capture of CO₂ the selected sorbent must satisfy the following conditions: i) large CO₂ uptake, ii) fast adsorption kinetics, iii) good selectivity against other molecules (i. e. N₂) competing for the adsorption sites and iv) easy regeneration. In the previous section we discussed the capture capacities of the carbon sorbents. Now, the other issues will be addressed. Figure 6 shows the adsorption kinetics of CO₂ and N₂ over the AS-2-600 carbon sample at 25°C. These measurements were carried out in a thermogravimetric system, as described in the experimental section. It can be seen that CO₂ adsorption is very fast, around 95 % of CO₂ uptake occurring in the space of 2 min. By contrast, N₂ adsorption is slower, around 60 min being needed for maximum adsorption uptake to take place (0.89 mmol N₂·g⁻¹). This result is interesting because evidences that high CO₂/N₂ selectivities can be achieved for short adsorption times. In fact, the [CO₂/N₂] selectivity measured under equilibrium conditions is 5.4 (see Fig. 6a), but kinetic selectivity measured at an adsorption time of ~ 2 min (~ 95 % of CO₂ uptake) is ~ 9. This result shows that CO₂ and N₂ can be effectively separated operating with short adsorption cycle times, which would be highly advantageous for practical applications.

Easy regeneration is another critical property that must be considered when designing CO₂ sorbents. In this respect, porous carbons offer certain advantages over other sorbents, such as zeolites. Because of the weak interactions between CO₂ and carbon (heat of adsorption ~ 20 kJ mol⁻¹) entailing low energy requirements, their regeneration is relatively easy. The regeneration of the carbon sorbents here were tested by means of adsorption (CO₂ at 1atm)-desorption (under helium) cycles carried out at room temperature (25°C). The results

of the tests for the AS-2-600 sample are illustrated in Figure 6b. It can be seen that the captured CO₂ is quickly desorbed after the gas carrier has been switched from CO₂ to He. In fact, > 95 % of CO₂ is desorbed within 3 min under these conditions. This adsorption-desorption cycle was repeated seven times and no noticeable changes were observed in the desorption kinetics or CO₂ uptake. In short, the porous carbons reported here can be easily, quickly and totally regenerated over multiple cycles without any loss of adsorption capacity.

Conclusions

In summary, we have demonstrated that sustainable porous carbons can be easily prepared from hydrothermally-treated polysaccharides (starch and cellulose) or biomass (sawdust) by chemical activation using KOH as activating agent. The CO₂ adsorption properties, kinetics and regeneration of these materials were investigated. The results of our study show that porous carbons prepared using mild activation conditions (KOH/HC=2) exhibit very high CO₂ adsorption uptakes. Specifically, the sample obtained at an activation temperature of 600°C shows an exceptionally high capacity to store CO₂ at room temperature (4.8 mmol·g⁻¹ at 25°C and 1 atm). This remarkable capacity to adsorb CO₂ is principally due to the presence of narrow micropores (< 1 nm), with surface area playing a less important role. Furthermore, these porous carbons exhibit a high CO₂ adsorption rate, a good selectivity for CO₂-N₂ separation and can be easily regenerated.

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Table 1. Textural properties of activated carbons derived from saccharides and sawdust.

Sample	S_{BET} [$\text{m}^2 \text{g}^{-1}$]	S_{micro} [$\text{m}^2 \text{g}^{-1}$] ^a	V_{p} [$\text{cm}^3 \text{g}^{-1}$] ^b	V_{micro} [$\text{cm}^3 \text{g}^{-1}$] ^a	V_{o} [$\text{cm}^3 \text{g}^{-1}$] ^c	Pore size [nm] ^d
AA-4-700	2190	2080	1.01	0.92	0.35	1.2
AC-4-700	2370	2200	1.08	0.96	0.37	1.2
AS-4-600	2370	2050	1.15	0.91	0.31	1.3
AS-4-700	2250	2090	1.03	0.91	0.35	1.2
AS-4-800	2850	2720	1.35	1.23	0.35	1.2/2.1
AS-2-600	1260	1360	0.62	0.61	0.52	0.8
AS-2-650	1380	1360	0.67	0.61	0.54	0.8
AS-2-700	1390	1360	0.69	0.62	0.60	0.9
AS-2-800	1940	1840	0.97	0.82	0.45	0.9

^a Evaluated by the t-plot method; ^b Total pore volume at $p/p_0 \sim 0.99$; ^c Pore volume of narrow micropores (< 0.7 nm) obtained from the CO_2 adsorption data at 0°C ; ^d Maxima of the PSDs calculated by NLDFIT assuming slit-shaped pores.

Table 2. CO₂ capture capacities of the porous carbons at different adsorption temperatures and 1 atm.

Sample	CO ₂ uptake, mmol·g ⁻¹ (mg·g ⁻¹)		
	0°C	25°C	50°C
AA-4-700	5.6 (247)	3.5 (152)	2.2 (96)
AC-4-700	5.8 (256)	3.5 (155)	1.8 (79)
AS-4-600	5.2 (230)	2.9 (128)	-
AS-4-700	5.5 (243)	2.9 (128)	1.8 (79)
AS-4-800	5.2 (227)	3.0 (130)	-
AS-2-600	6.1 (270)	4.8 (212)	3.6 (158)
AS-2-650	6.0 (262)	4.7 (206)	3.3 (145)
AS-2-700	6.6 (288)	4.3 (190)	2.6 (116)
AS-2-800	5.8 (255)	3.9 (170)	3.1 (136)

Table 3. Comparison of CO₂ uptakes (25°C and 1 atm) for different porous carbon sorbents.

Sorbent	CO ₂ uptake mmol g ⁻¹ (mg g ⁻¹)	Reference
Commercial activated carbon (BPL)	2.1 (92)	3
Commercial activated carbon (G-32 H)	2.5 (110)	26
Ammonia treated activated carbon (C35N400)	1.7 (76)	18
Activated graphite fibres (G-900)	1.3 (59)	27
Mesoporous carbon (CMK-3)	1.7 (76)	28
N-doped activated carbon (MFB-600)	2.3 (101)	19
Ammonia treated activated carbon (RN800)	2.2 (96)	29
N-doped porous carbon (RFL-500)	3.1 (136)	20
Activated carbon from petroleum pitch (DO-88-M)	4.7 (207)	21
Sawdust-based porous carbon (AS-2-600)	4.8 (212)	This work

Figure Captions

Figure 1. SEM images of (a) eucalyptus sawdust, (b) HC-starch, (c) HC-cellulose, (d) HC-sawdust and (e) AS-4-800 activated carbon, and TEM image of the AS-4-700 sample (f).

Figure 2. N₂ sorption isotherms and pore size distributions (insets) for the activated carbons prepared from hydrochar samples derived from starch, cellulose and sawdust.

Figure 3. N₂ sorption isotherms (a, c) and pore size distributions (b, d) of activated carbons prepared from HC-sawdust at different activation temperatures and (KOH/HC) weight ratios of 4 (Fig. a and Fig. b) and 2 (Fig. c and Fig. d).

Figure 4. Comparison of CO₂ adsorption isotherms at 25°C for hydrochar-based porous carbons and a commercial activated carbon (M-30).

Figure 5. CO₂ adsorption isotherms at 0°C (○), 25°C (□) and 50°C (Δ) for the porous carbons obtained when KOH/HC=2 at the following activation temperatures: (a) 600°C (AS-2-600), (b) 650°C (AS-2-650), (c) 700°C (AS-2-700) and (d) 800°C (AS-2-800).

Figure 6. (a) Adsorption kinetics of CO₂ and N₂ at 25°C for the AS-2-600 sample and (b) CO₂ Adsorption-desorption cycles obtained for the AS-2-600 sample at 25°C (CO₂ concentration: 100 %).

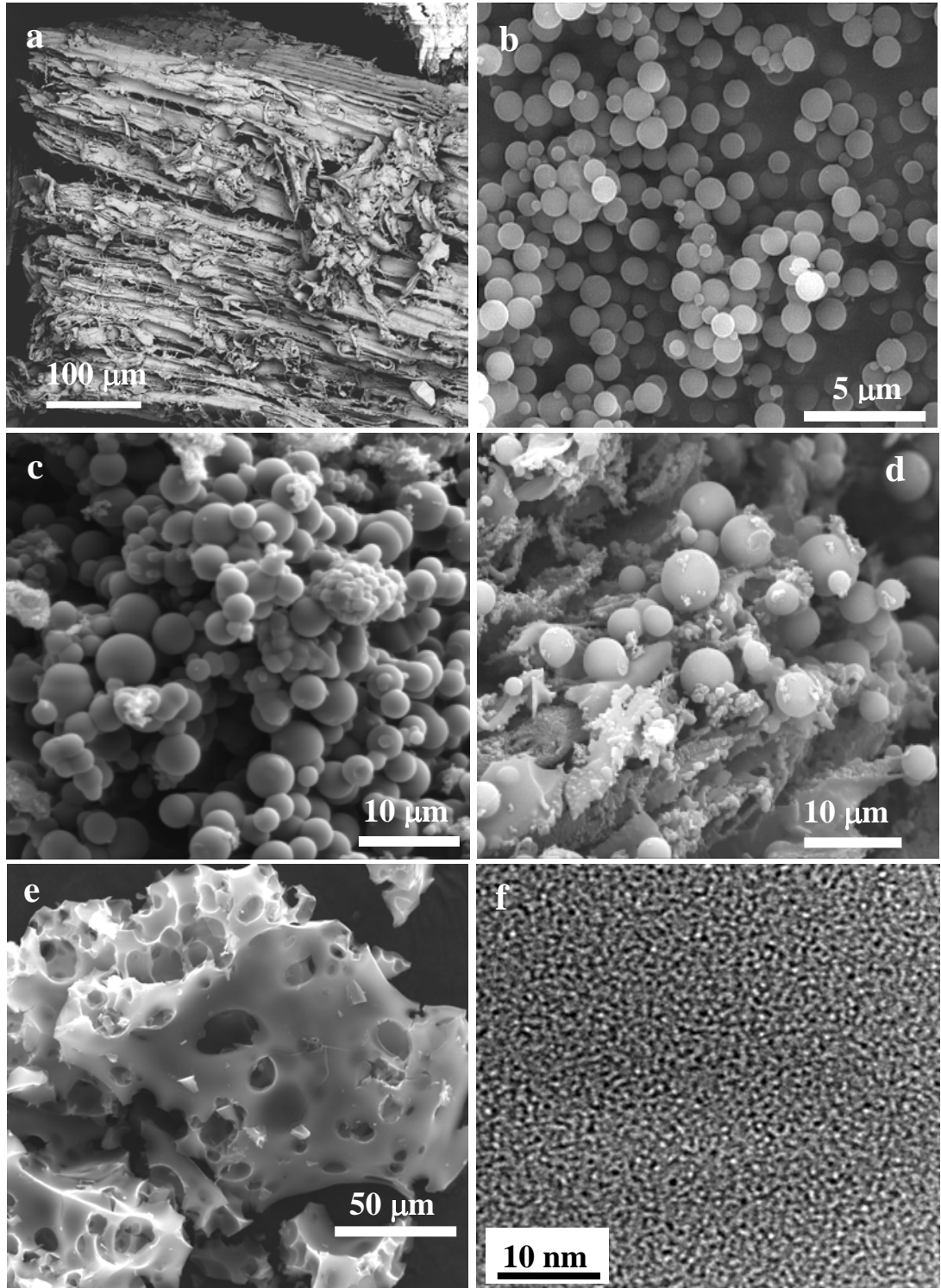


Figure 1

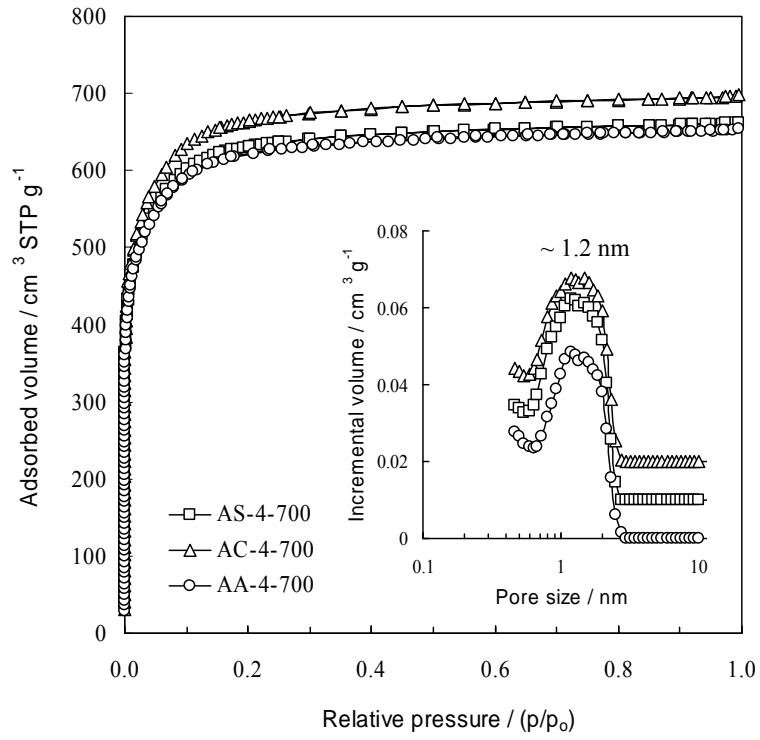


Figure 2

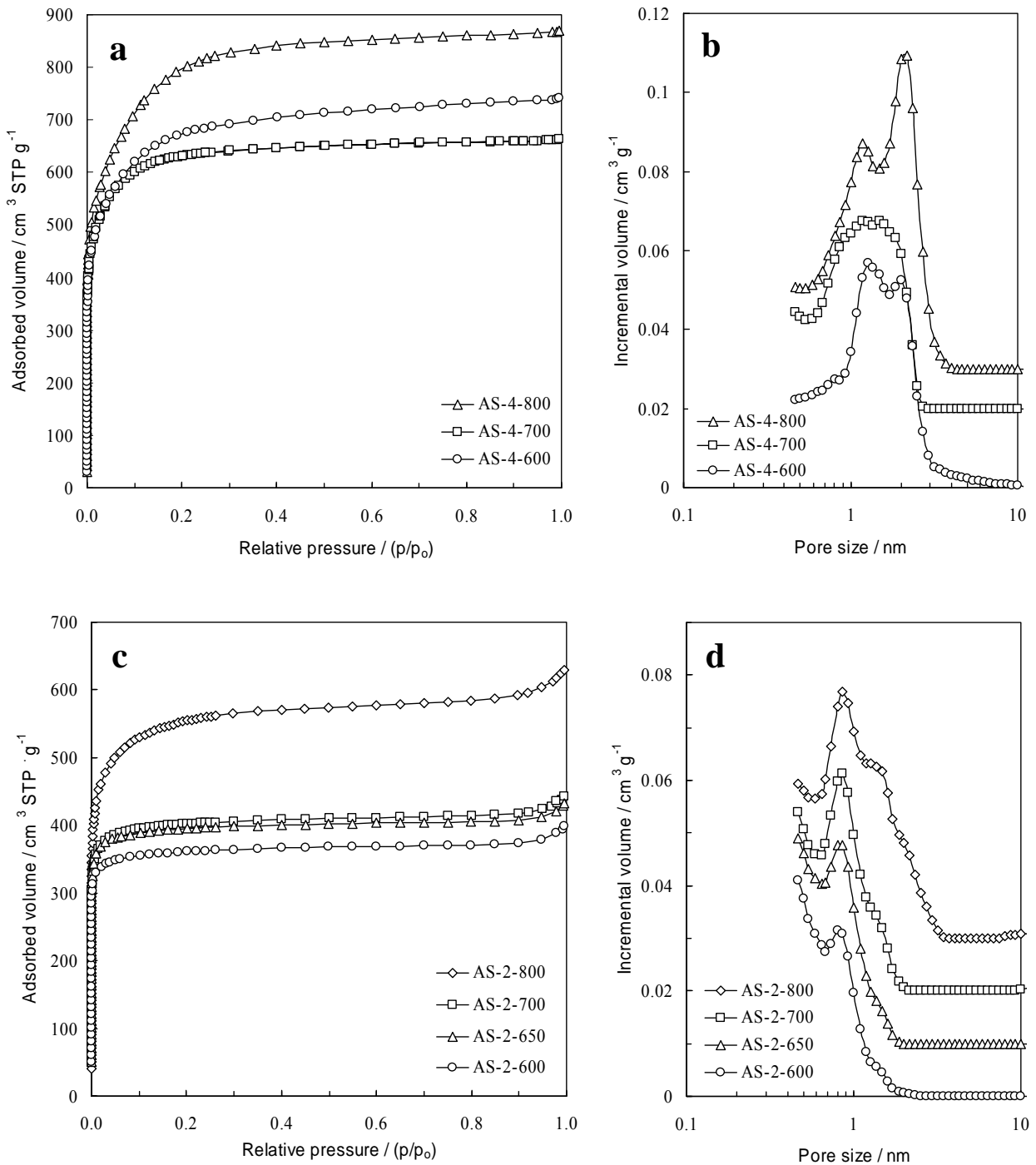


Figure 3

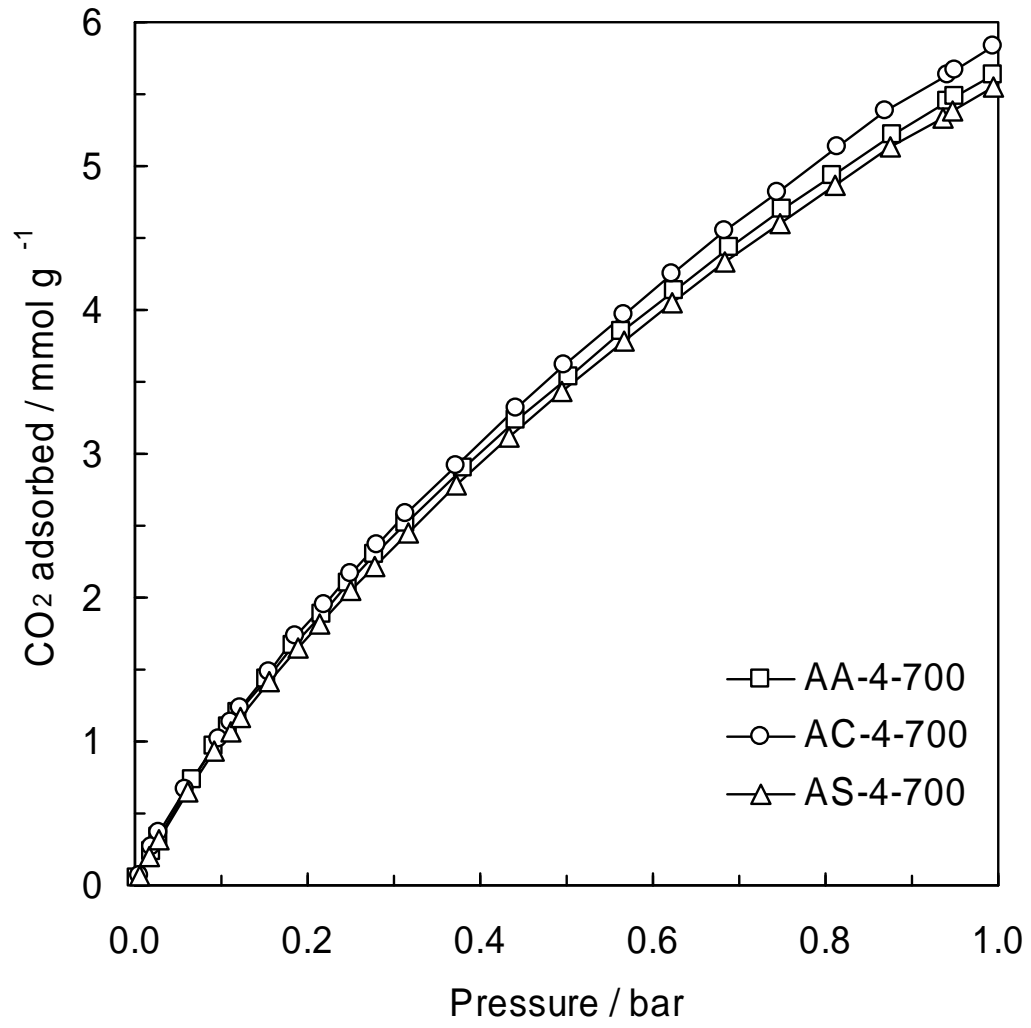


Figure 4

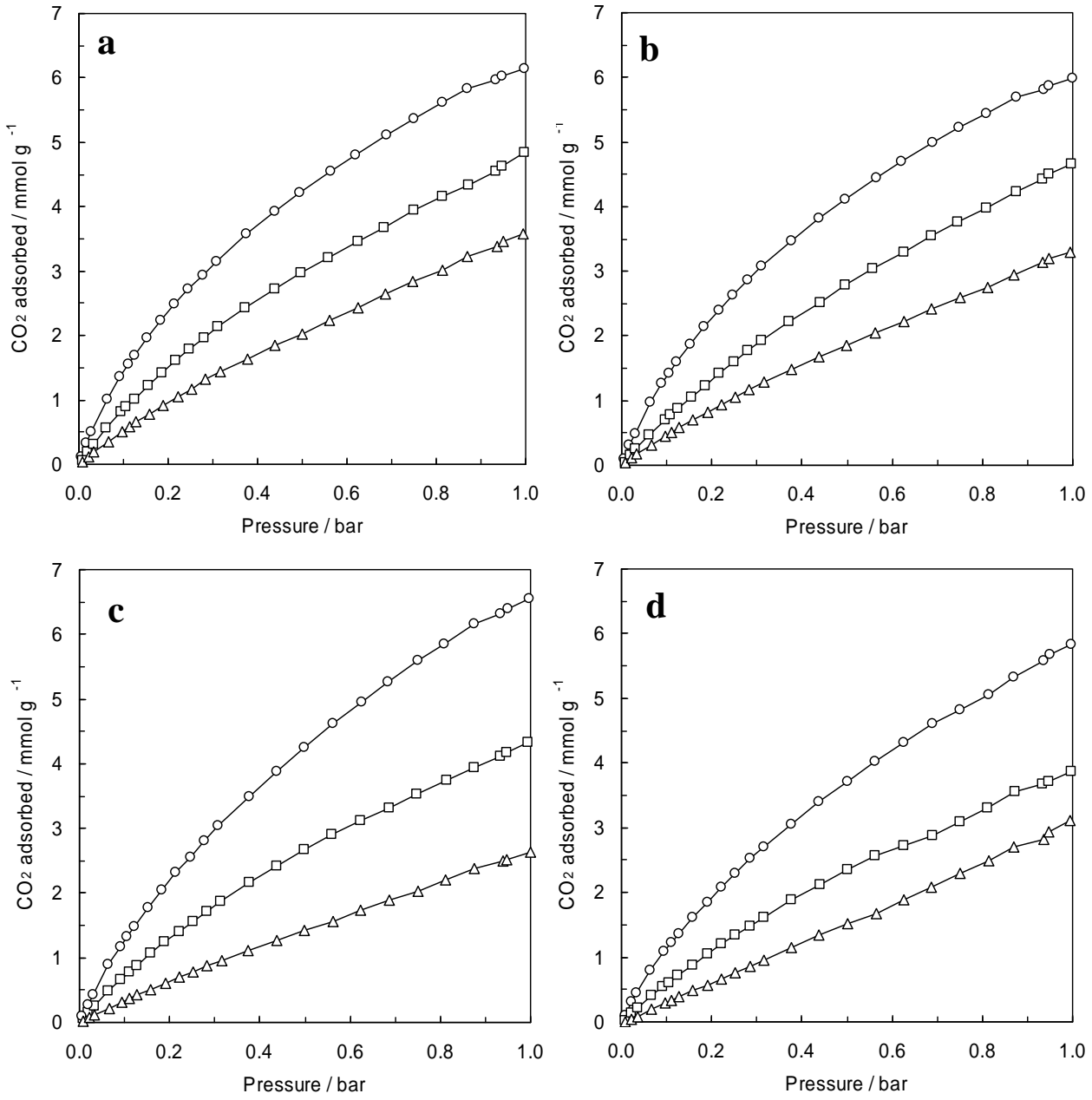


Figure 5

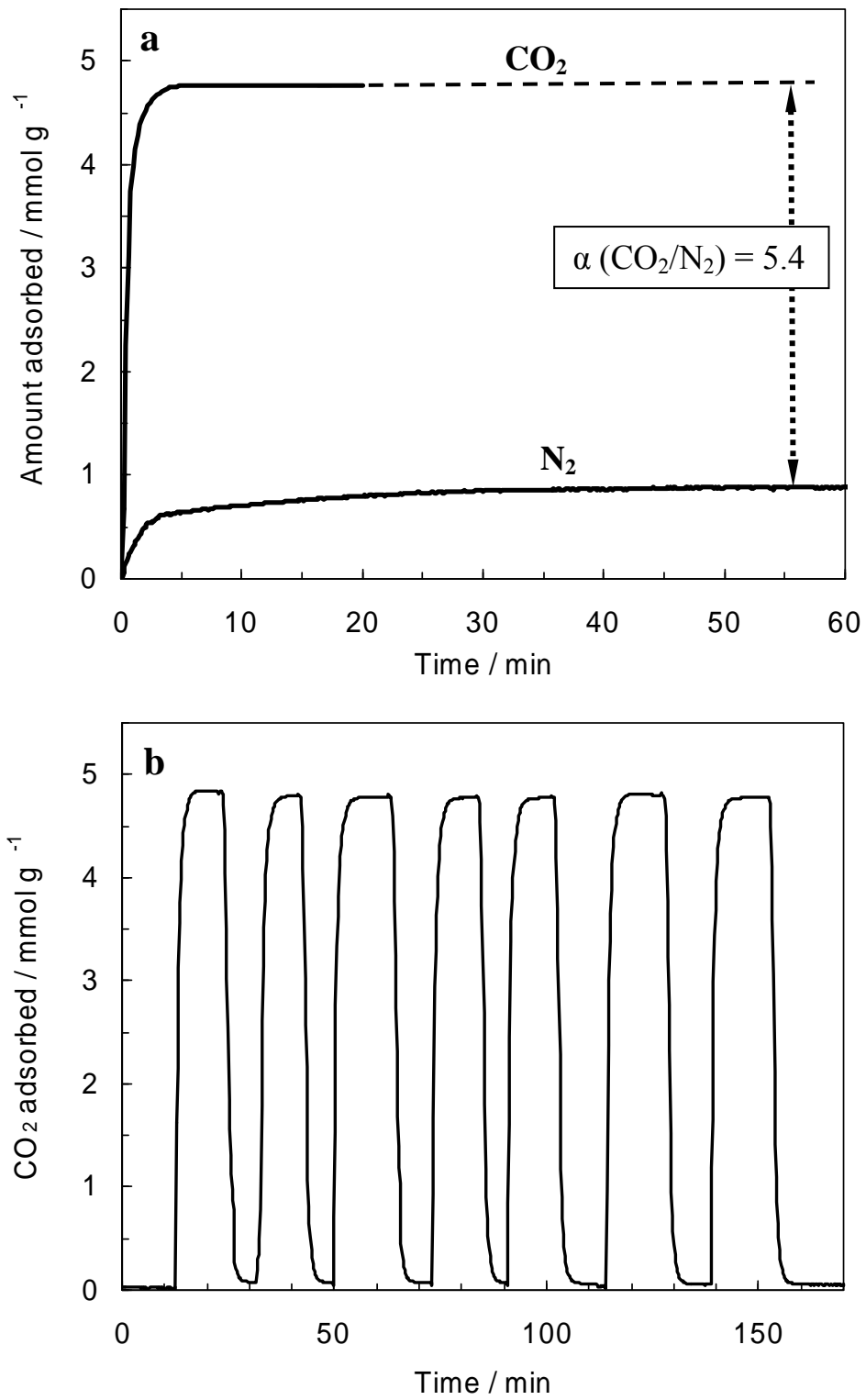


Figure 6

Graphical Abstract

The preparation and characterization of carbon-based CO₂ porous sorbents obtained from a low-cost sustainable biomass product (sawdust) is presented. These sorbents exhibit high CO₂ uptakes, fast sorption kinetics and easy regenerability.

