ACCSCIENCE PUBLISHING

Asian Journal of Water, Environment and Pollution

ORIGINAL RESEARCH ARTICLE

Comparative study on the CO_2 capture performance of sludge pyrolysis biochar prepared with different inorganic dehydrating conditioners

Supplementary Files

S1. Key measurement parameters and test methods for sludge dewatering

(i) Determination of the specific resistance to filtration

The determination of sludge-specific resistance employs the Büchner funnel method. The principal procedure involves pouring 100 mL of the conditioned sludge sample into a Büchner funnel with a diameter of 9 cm. A filtration pressure of 0.030 MPa was applied, ceasing when the qualitative filter paper reached a vacuum state. During filtration, the volume of filtrate corresponding to different time points was recorded. The calculation formula is shown in **Equation S1**:

$$SRF\left(m/kg\right)=\frac{2PA^2b}{\mu\omega} \tag{S1}$$

In the formula, P denotes the filtration pressure (N/m^2);

A denotes the filtration area (m^2);

b denotes the slope of the filtration linear V-t/V curve (N/m^2);

μ denotes the dynamic viscosity coefficient of the filtrate (N·s/m^2).

The Oersted viscometer was placed in a thermostatic bath at (25±0.1) °C. After stabilising for 5–10 mins, conduct three parallel tests per operation, ensuring each test is performed within 0.3 s of the preceding one. The average value was calculated as shown in **Equation S2**.

$$\eta_x=\frac{t_{22}}{t_1\rho_1}\eta_0 \tag{S2}$$

At 20 °C, the density ρ_1 of pure water is 0.998203 g/cm^3, and its dynamic viscosity η_0 is 1.0016 mPa·s. ω denotes the mass of solids (kg/m^3) retained on the filter medium per unit filtration area.

(ii) Determination of filter cake moisture

A total of 100 mL of conditioned sludge sample was measured using a graduated cylinder and poured into a Büchner funnel. A filtration pressure of 0.030 MPa was maintained during vacuum filtration for dewatering. The filtration was ceased once the qualitative filter paper reached a vacuum state. The retained portion was transferred from the filter paper into a pre-weighed flask, weighed, and recorded. The weighing bottle was placed in an oven at 105(±5) °C until a constant weight was achieved. The calculation formula is as shown in **Equation S3**:

$$FCM\left(\%\right)=\frac{m_1-m_2}{m_1-m}\times100\% \tag{S3}$$

In the formula: m denotes the mass of the weighing bottle (g);

m_1 denotes the mass of the filter cake plus the weighing bottle before drying (g);

m_2 denotes the mass of the dried sludge cake plus the weighing bottle (g)

(iii) Sludge settling ratio (SV_{30})

Sludge settling ratio denotes the volume ratio of settled sludge to the original sludge mixture after 30 mins of settling for 100 mL of sludge mixture. A lower SV_{30} value indicates superior sludge settling performance. The calculation formula for SV_{30} is shown in **Equation S4**:

$$SV_{30}(\%) = \frac{V}{100} \times 100\% \tag{S4}$$

In the formula: SV_{30} denotes the sludge sedimentation ratio (%);

V denotes the volume of settled sludge (m^3).

S2. Analysis of carbon dioxide adsorption data on sludge biochar

(i) Carbon dioxide adsorption by biochar

The adsorption of biochar for CO_2 was calculated as in **Equation S5**:

$$Q = \frac{q_{1-}q_2}{q_1} \times 1000 \tag{S5}$$

In the formula: Q is the adsorption amount of biochar (mg/g);

q_1 is the initial weight of biochar (mg);

q_2 is the weight of CO_2 adsorbed biochar (mg)

(ii) Fitting the kinetic model

A quasi-primary kinetic model, as shown in **Equation S6**, a quasi-secondary kinetic model, as shown in **Equation S7,** and an Avrami model, as shown in **Equation S8**, were used to fit the adsorption data.

$$q_1 = q_e\left(1 - e^{\frac{-k_1 t}{2.303}}\right) \tag{S6}$$

$$q_1 = \frac{k_2 t q_e^2}{1 + k_2 t q_e} \tag{S7}$$

$$q_t = q_e\left(1 - e^{-(kt)^n}\right) \tag{S8}$$

In the formula: q_t is the CO_2 content adsorbed by biochar at time t (mg/g);

q_e is the amount of CO_2 adsorbed by the biochar when adsorption reaches equilibrium (mg/g);

t is the time of CO_2 adsorption by biochar;

k_1 is the quasi-primary kinetic constant; k_2 is the quasi-secondary kinetic constant;

k, t, n are the relevant adsorption rate constants

S3. Characterisation of biochar and its mechanistic analysis

Morphological and microstructural features of the biochar samples were investigated using scanning electron microscopy. Mineral phases were analysed using X-ray diffraction. Surface area, pore size distribution and isothermal adsorption and desorption profiles were measured using the Brunauer–Emmett–Teller method. Surface functional groups were examined using Fourier transform infrared spectroscopy. The inductively coupled plasma technique was used to study the morphological changes of heavy metals before and after CO_2 capture by biochar.

S4. High-resolution Fe 2p X-ray photoelectron spectroscopy analysis of sludge-derived biochar

The high-resolution Fe 2p XPS spectra (Figure S1) were collected to analyze the chemical state of iron species in biochar prepared from raw sludge (SS) and sludge conditioned with different inorganic agents (PFS, PSAF, PFC). The Fe 2p signals are clearly observed in all samples, confirming the presence of iron derived from the conditioning agents and sludge matrix. The smoothed curves further reveal the overall distribution trend of iron species across different binding energies, which reflects the influence of conditioning methods on the iron speciation in the final biochar.

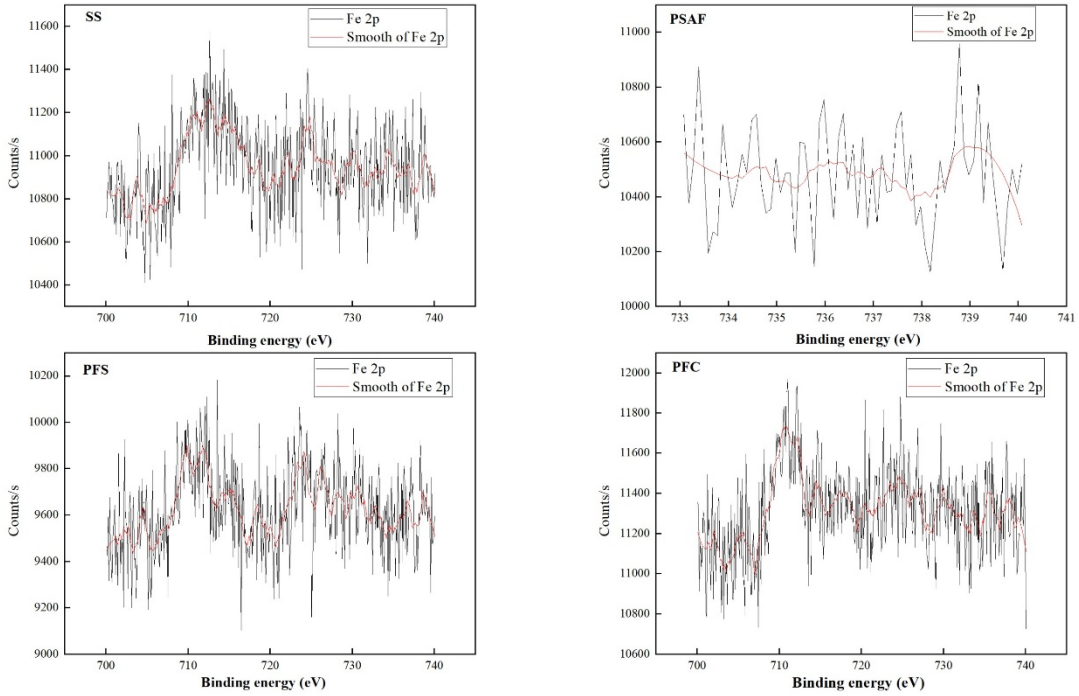

Figure S1. High-resolution Fe 2p X-ray photoelectron spectroscopy spectra of biochar from sludge treated using different methods

S5. The phase composition of biochar

Figure S1 displays the crystalline phase composition of each biochar sample. The inorganic mineral phases primarily comprise silicon dioxide (SiO_2) and silicon carbide. At $2\theta = 26.7°$, all biochars exhibit corresponding peaks. It is evident that the peaks for SS-PFS_{cycle}, SS-PSAF conventional, and SS-PFC_{cycle} biochars are markedly lower than those of the original sludge biochar. The sharpness of the SiO_2 diffraction peak diminished, indicating reduced crystalline peak intensity. Within the 2θ =20°–40° range, the baseline exhibited a marked elevation, forming a broad peak. This is a characteristic feature of amorphous substances. This transition from a crystalline state to an amorphous state indicates that a chemical reaction has occurred during the CO_2 adsorption cycle. This may be due to the metal oxides introduced by the conditioning agent reacting

with CO_2 and moisture to form amorphous metal carbonates or bicarbonates. The absence of sharp carbonate peaks in the X-ray diffraction pattern precisely indicates that the resulting products are amorphous and highly dispersed, reflecting high reactivity. The newly formed amorphous carbonates possess a higher specific surface area and a greater number of active sites, elevating the adsorption mechanism from physical to chemical adsorption. This facilitates enhanced CO_2 uptake. Among the samples, SS-PFS cycled biochar exhibits the most pronounced non-crystallisation, thereby demonstrating the strongest CO_2 adsorption capacity.

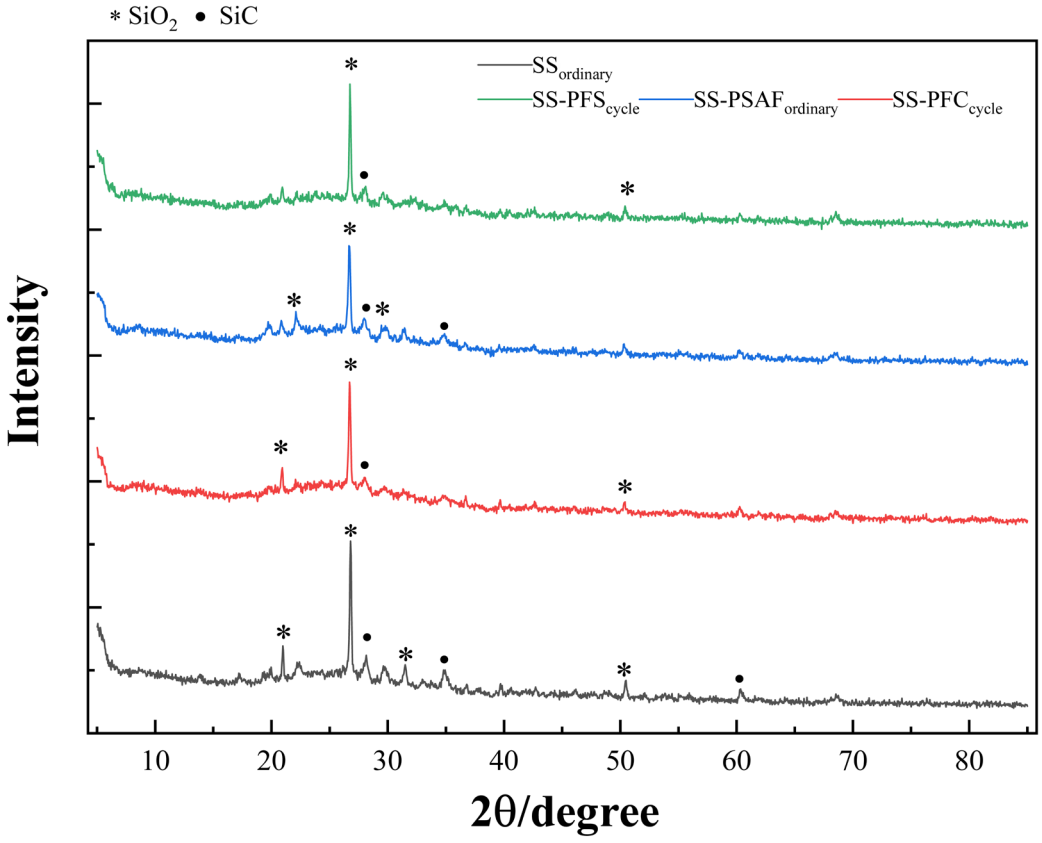

Figure S2. X-ray diffraction pattern of biochar
Abbreviations: PFC: Polyferric chloride; PFS: Polyferric sulfate; PSAF: Polyaluminosilicate ferric salt; SiC: Silicon carbide; SiO_2: Silicon dioxide; SS: Raw sludge.