

Supporting Information

Penicillin fermentation residue biochar as a high-performance desalination electrode for membrane capacitive deionization

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S1. Energy budget

S1.1 effective carbon yield

The effective carbon yield (ECY, (Eq. S1)) was calculated as below:

$$\begin{aligned} ECY &= \frac{\text{mass of final product}}{\text{mass of hazardous and toxic reagent}} \\ &\times 100\% \end{aligned} \quad (S1)$$

Here, ECY is the effective carbon yield of PFRB, (%); The final product can be used to make electrode sheet directly.; The mass of hazardous and toxic reagent includes the mass of penicillin fermentation residue and the mass of potassium carbonate, (g). ECY was calculated to be 5.7%.

S1.2 Mass intensity

The mass intensity (MI, (Eq. S2)) was calculated as below:

$$\begin{aligned} MI &= \frac{\text{total mass of used in a process or process step}}{\text{mass of final product}} \end{aligned} \quad (S2)$$

Here, MI is the mass intensity of PFRB, (kg/kg); The total mass of used in a process or process step includes the mass of penicillin fermentation residue and potassium carbonate as well as the quality water (g). MI was calculated to be 6.97 kg/kg.

S2. Desalination performance evaluation

S2.1 salt removal rate

The salt removal rate (SRR, (Eq. S1), salt adsorption divided by total salt mass) was calculated as below:

$$SRR = \frac{C_0 - C_t}{C_0} \times 100\% \quad (S3)$$

Here, SRR is the salt removal rate, (%); C_0 is the initial concentration, ($\text{mol}\cdot\text{L}^{-1}$); C_t is the conductivity at time t , ($\text{mol}\cdot\text{L}^{-1}$).

S2.2 Charge efficiency

The charge efficiency (CE, Eq. S2) is defined as the molar ratio of salt removed over the amount of charge transferred through the cell. The charge efficiency was calculated as below:

$$CE = \frac{(C_0 - C_t) \times V \times n \times F}{\int I dt} \quad (S4)$$

Here, CE is charge efficiency, (%); n is the charge of cation and anion, Na⁺ and Cl⁻ are both 1. F is Faraday constant (96485 C·mol⁻¹); I is the current(A).

S2. 3 salt adsorption capacity

The salt adsorption capacity (SAC, Eq. S3) was evaluated as below:

$$SAC = \frac{(C_0 - C_t) \times V \times 58.5 \times 10^3}{m} \quad (S5)$$

Here, SAC is adsorption capacity(mg·g⁻¹); V is the volume of solution(L); m is the mass of the electrode, g.

S2. 4 Average salt adsorption rate

The desalination amount per unit time per unit electrode area is expressed by the average salt adsorption rate (ASAR, Eq. S4) and calculated as below:

$$ASAR = \frac{(C_0 - C_t) \times V \times 10^6}{S \times t} \quad (S6)$$

Here, ASAR is the average desalination rate(μmol·cm⁻²·min⁻¹); S is the electrode area (cm²); t is time(min).

S2. 5 Specific energy consumption

The amount of salt removed per unit of energy is expressed in terms of specific energy consumption (SEC). The SEC (Eq. S5) was calculated as below:

$$SEC = \frac{(C_0 - C_t) \times V \times 10^6}{U \times \int Idt} \quad (S7)$$

Here, SEC is the specific energy consumption(μmol·J⁻¹); U is the voltage(V).

S3. Electrochemical characterization evaluation

In order to characterize the electrochemical characteristics of the biochar electrode, the cyclic voltammetry of the biochar electrode was measured by three-electrode system.

The calculation formula of specific capacitance (Eq. S6) was as follow:

$$C = \frac{\int IdV}{m \times \Delta V \times v} \quad (S8)$$

Here, I is the response current(A); m is electrode mass(g); v is the scanning rate (V s⁻¹); ΔV is the potential difference(V).

S4. SEM image and organic element content

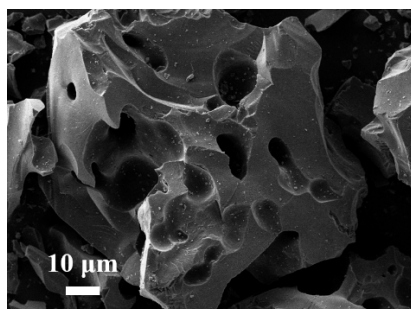


Fig.1 SEM image of the PFRB-700 material without activation agent

Table S1 analysis of organic element in penicillin fermentation residue

Material	C (%)	O (%)	N (%)
penicillin fermentation residue	40.43	30.32	9.21

S5. Water contact angle measurement

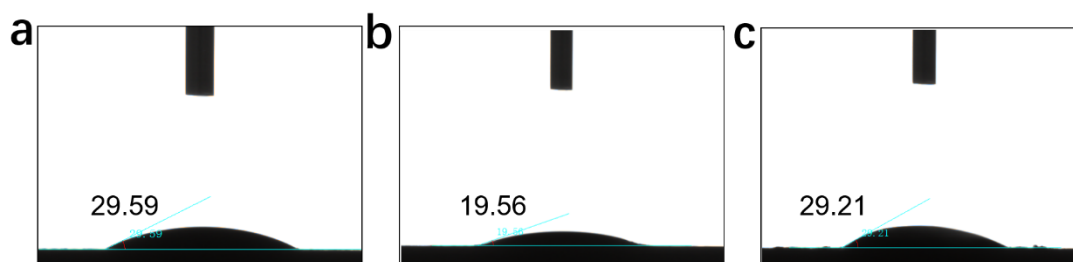


Fig. S2 static contact angles on the electrode surface of (a) PFRB-600, (b) PFRB-700 and (c) PFRB-800

S6. Raman spectroscopy

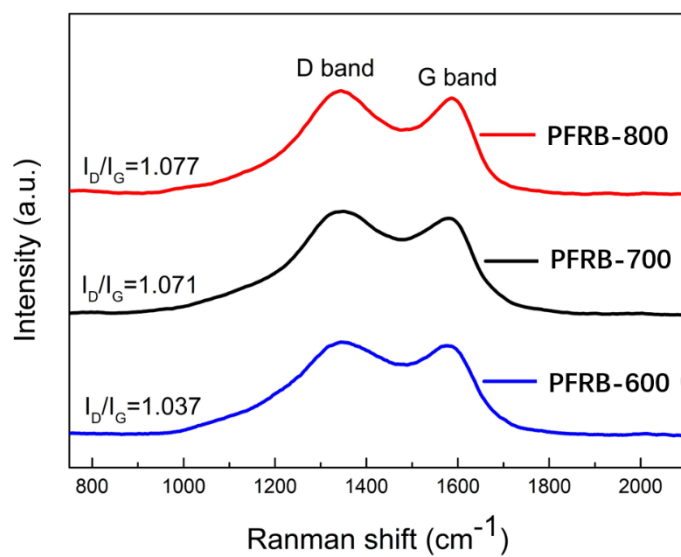


Fig. S3 Raman spectra of PFRBs at different carbonization temperatures.

S7. X ray photoelectron spectroscopy

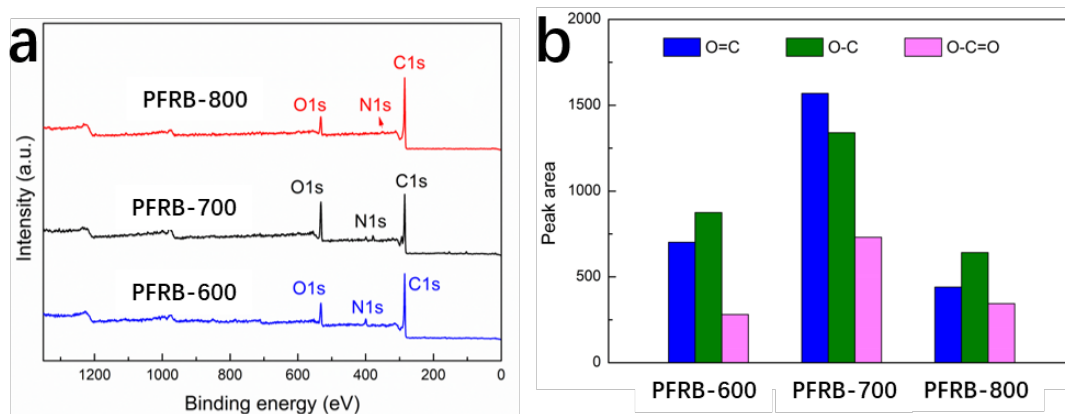


Fig. S4 (a) full spectrum of PFRB at different carbonization temperatures; (b) peak areas of O1s of PFRB-600, PFRB-700 and PFRB-800

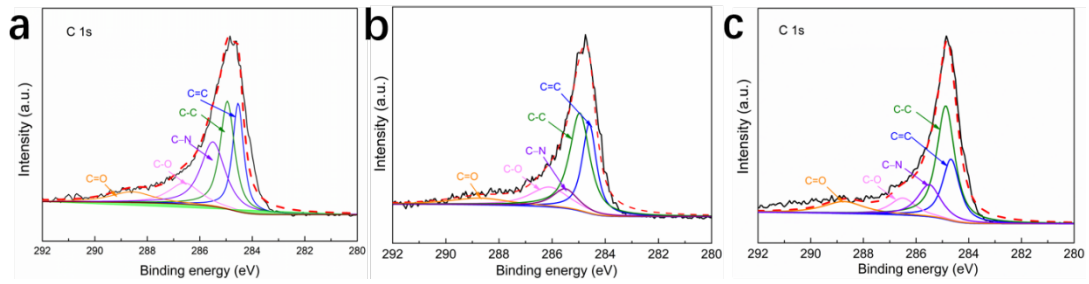


Fig. S5 the the C1s peak of (a) PFRB-600, (b) PFRB-700 and (c) PFRB-800

S8. Desalination experiments

S8. 1 Effect of electrode weight on the desalination performance of the MCDI system

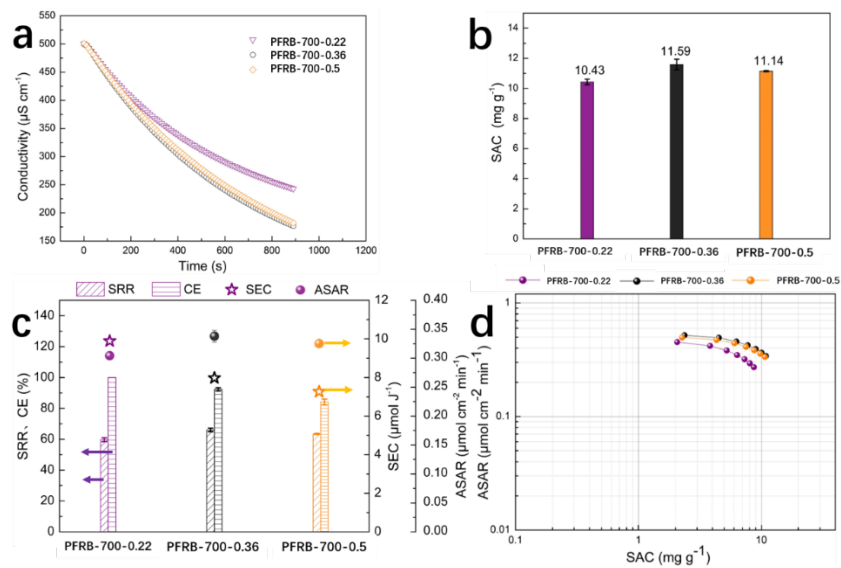


Fig. S6 Influence of electrode quality on the desalination performance of the MCDI system. (a) Change in conductivity of PFRB-700 with different masses over time; (b) SAC of PFRB-700 with different masses; (c) SRR, CE, ASAR, and SEC of different mass electrodes; (d) Ragone diagram of PFRB-700 with different masses.

S8. 2 Effect of voltage on the desalination performance of the MCDI system

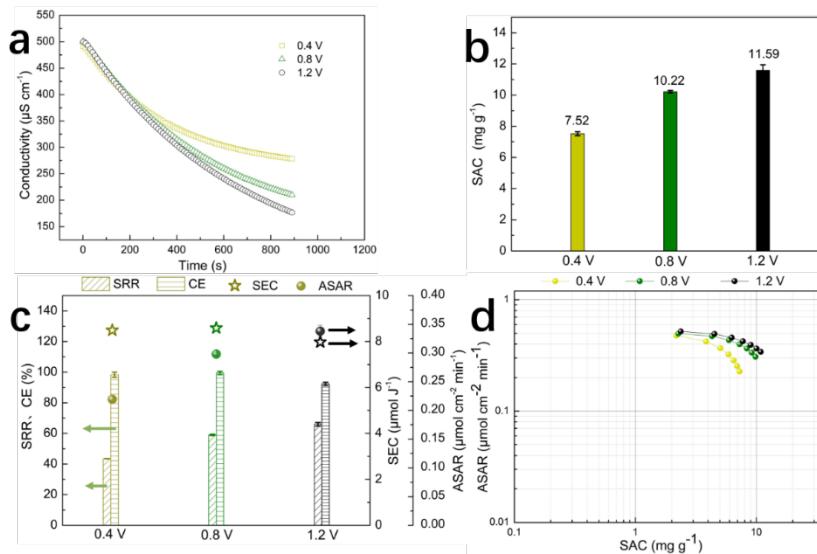


Fig. S7 Influence of different operation voltages on desalination performance. (a) Change in conductivity of PFRB-700-0.36 with time at different voltages; (b) SAC of PFRB-700-0.36 at different operation voltages; (c) SRR, CE, ASAR, and SEC of PFRB-700-0.36 at different operation voltages; (d) Ragone diagram of PFRB-700-0.36 at different operating voltages.

S9. Performance comparison table

Table S2 Comparison of the electro-adsorption performance of various materials

Electrode material	Surface area (m^2/g)	Salt solution	C_0 (mg/L)	Adsorption Capacity (mg/g)	Reference
Porous carbon					
Derived from activated biochar	1839	Sodium chloride	1170	8.11	[1]
Activated carbon derived from crude residual glycerol	1684	Sodium chloride	600	27.1	[2]
Co and Titania	670.3	Sodium	75	12.48	[3]

nanoparticle-intercalated rGO		chloride			
Three-dimensional graphene	1492.8	Sodium chloride	100	9.37	[4]
Nitrogen,phosphorus co- doped porous carbon	1044	Sodium chloride	500	24.14	[5]
Commercial activated carbon	2000	Sodium chloride	250	6.94	Commercial activated carbon experiment
Commercial graphene	17.59	Sodium chloride	250	0.58	Commercial graphene experiment
Commercial carbon nanotubes	126.89	Sodium chloride	250	3.47	Commercial carbon nanotubes experiment
PFRM-600	537	Sodium chloride	250	7.37	This study
PFRM -800	2118	Sodium chloride	250	9.05	This study
PFRM -700	1171	Sodium chloride	1000	26.4	This study

References

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