Supporting Information

Vasculatural Hydrogel Combined with Prussian Blue for Solar-Driven Vapor

Generation

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1. Experiments

1.1 Synthesis of polyacrylamide (PAAm) hydrogel

The hydrogel was synthesized according to a previous report ¹. In particular, 1.8768 g acrylamide (monomer), 1.128 mg *N*,*N'*-methylenebis(acrylamide) (cross-linkers), 3.196 mg ammonium persulfate (photoinitiator) and 6 μ L *N*,*N*,*N'*,*N'*-tetramethylethylenediamine (cross-linking accelerator) were dissolved in 12 mL deionized water first. After degassing with sonication, poured the solution into a glass microbial culture dish (Φ 90 mm) and covered with a silica glass (100 × 100 × 3 mm). Then the solutions in the dish were cured with UV light for 1 h with power 50 W and 395 nm wavelength. The obtained hydrogel has been cut into different sizes and purification in deionized water to remove unreacted monomers.

1.2 Characterization of Prussian blue (PB)

D8 ADVANCE Da Vinci automated diffraction systemwith Cu K_{α} radiation ($\lambda = 1.5416$ Å) was applied to collect the powder X-ray diffraction patterns (PXRD) of all compounds in the power of 40 kV and 25 mA (Bruker, Germany). Measurements were made in a 2θ range of 4–45° at room temperature with a step of 0.06° (2θ) and scanning speed of 5 °·min⁻¹. In X-ray photoelectron spectroscopy (XPS, K-AlphaTM Plus, ThermoFisher, USA) study, photoelectrons generated by Al K_{α} (1486.8 eV) primary radiation (20 kV, 10 mA) were analyzed with a hemispherical analyzer, and core-level XPS for C 1s, N 1s, and Fe 2p were recorded and fitted. Binding energy was calibrated with the standard C 1s (hydrocarbon C–C, C–H) value of 284.8 eV. Data were quantitatively assessed using a one-way factorial analysis of the variance method. The surface morphology of the samples was investigated by using scanning electron microscopy (SEM, JSM-7610F Plus, JEOL, Japen) at acceleration voltage 10.0 kV.

Thermogravimetric (TG) analysis was conducted using a Mettler TGA/DCS3⁺ instrument, with a heating rate of 10 °C min⁻¹ under an air atmosphere (Switzerland).

The stability of PB was investigated from two aspects of irradiation stability and saline erosion resistance. For irradiation stability, a xenon arc lamp (Microsolar 300, PerfectLight, Beijing, China) was used as the irradiation source. PB powder (20 mg) was tiled in a porcelain boat with a bottom area of 0.25 cm² and irradiated at 3 Sun solar flux (AM1.5, 3 kW m⁻¹) for a period, and then evaluated the crystallographic structure integrity of PB using the PXRD as the evaluation standard. In addition, the immersion test was performed to examine the long-term saline erosion performance of the PB. The samples were immersed in the saline (0–10 wt%) at room temperature for 100 d. The ratio of the sample mass to the solution volume was 400 µg mL⁻¹. The concentration of the Mg element in the solution was tested by atomic absorption spectrophotometer (AAS, TAS-990F, Persee, Shanghai, China). A minimum of three replicate measurements was performed for each concentration group to ensure reproducibility ($n \ge 3$).

1.3 Properties of hydrogels

For characterization of the micro- and nanostructure of the hierarchically aligned hydrogels, all hydrogels samples were immersed in deionized water for 72 h before freeze-drying using a SCIENTZ-10N (SCIENTZ, Ningbo, China) freeze-dryer. The freeze-dried hydrogels were cut along the aligned direction to expose their and sputtered with gold before conducting imaging using a JSM-7610F Plus SEM at acceleration voltage 15.0 kV.

In order to study the capillary force of the different gels on water, the wetting behavior of the hydrogels was tested. Meanwhile, the hydrogels were freeze-dried into aerogels for corresponding tests to avoid the interference of water contained in the hydrogels on the results.

Water contact angles on all samples were monitored by a sessile drop shape analysis instrument (DSA, Hamburg 100, KRÜSSGMBH, Germany) at room temperature. For each sample, a 5 μ L water droplet was added each time. Moreover, time-dependent contact angle changes on all hydrogels were monitored by DSA, and all data were collected from 0 to 300 s.

The wicking height was measured based on the reported literature ², of the samples (20 mm \times 10 mm) were dipped into deionized water in which methyl orange had been added to track the capillary rise. Photographs of the large-size aerogel and the horizontal water spreading process were taken by a digital camera. To demonstrate the directional water pumping process, a simplified demonstration model was established using a dynamic pumping process of a water droplet dyed with 0.1 wt% sodium fluorescein. For comparison, the hydrogel (aerogel) was dyed with 0.1 wt% rhodamine B. Observations were made in the presence of an ultraviolet lamp (295 nm, 3 W), and photographs were extracted from video taken by a digital camera.

In the hydrophilic porous media, the water transport following the Poisueille flow is driven by the capillary force (Eqution 1) and is resisted by the combination of viscous resistance (Eqution 2), self-gravity (Eqution 3), and inertial force (Eqution 4) $^{2-5}$:

$$F_{\rm c} = \frac{2\gamma\cos\theta}{r}\pi r^2 = 2\gamma\cos\theta\pi r \tag{S1}$$

$$F_{\rm v} = 2\pi r h(t) \tau = 2\pi r H^{\cdot}(t) \frac{4\mu v}{r} = 8\pi \mu H^{\cdot}(t) v_1$$
 (S2)

$$F_{\rm g} = \rho g H^{\cdot}({\rm t}) \pi r^2 \tag{S3}$$

$$F_{\rm i} = \frac{dmv_1}{dt} \tag{S4}$$

where γ is the surface tension of water in the air, θ is the contact angle between the water and inter-fiber channel, r is the radius of the channel, μ is the water viscosity, $H^{\cdot}(t)$ is the wicking height, v_1 is the wicking velocity, and ρ is the water density, respectively. Therefore, the force balance in the capillary pores can be expressed as:

$$F_{\rm c} - F_{\rm v} - F_{\rm g} - F_{\rm i} = 2\gamma \cos\theta\pi r - 8\pi\mu H^{\cdot}(t)v_1 - \rho g H^{\cdot}(t)\pi r^2 - \frac{dmv_1}{dt} = 0$$
(S5)

When the water wicking approaches its stationary level, the inertial effect can be ignored in this viscous regime. The force balance turns to:

$$F_{\rm c} - F_{\rm v} - F_{\rm g} = 2\gamma \cos\theta \pi r - 8\pi\mu H^{\cdot}(t)v_1 - \rho g H^{\cdot}(t)\pi r^2 = 0$$
(S6)

By solving the nonlinear differential equation, the capillary height H(t) can be written as:

$$H^{\cdot}(\mathbf{t}) = \frac{-2\gamma\cos\theta}{\rho gr} \left[1 - \exp(-\frac{\rho^2 g^2 r^3}{16\mu\gamma\cos\theta} t) \right]$$
(S7)

and the variation in v_1 with r can be rewritten as:

$$v_1 = \frac{\rho g r^2}{8\mu} \exp\left[-\frac{\rho^2 g^2 r^3}{16\mu\gamma\cos\theta}t\right]$$
(S8)

Additionally, for the horizontal spreading process, the self-gravity can be ignored and the force balance can be written as:

$$F_{\rm c} - F_{\rm v} = 2\gamma \cos\theta\pi r - 8\pi\mu L'(t)v_2 = 0 \tag{S9}$$

Similarly, the spreading distance L(t) can be written as:

$$L'(t) = \frac{r\gamma\cos\theta t}{2\mu}$$
(S10)

and the variation in spreading velocity v_2 with r can be rewritten as:

$$v_2 = \sqrt{\frac{r\gamma\cos\theta}{4\mu t}} \tag{S11}$$

Meanwhile, in this work, the pore size, shape, roughness, and distribution of the gels are very complicated. Unlike the capillary channels with a simple shape and completely closed walls, the capillary force in gels cannot be calculated simply by the average pore size. Therefore, we set an effective channel radius r_{eff} based on the effective medium approximate theory to describe the force of the capillary ⁶. By inputting the modified channel radius r_{eff} , the functions between the wicking velocity v_1 and r_{eff} can be written as:

$$v_1 = 0.48602 r_{eff}^2 \times \exp(-0.008698 r_{eff}^3)$$
(S12)

Similarly, the relationship between the spreading velocity v_2 and r_{eff} can be written as

$$v_2 = \sqrt{0.18326r_{eff}}$$
(S13)

which was shown in Figure 2d.

1.4 Equivalent vaporization enthalpy of water in PVA/PB with different concentrations of brine

To obtain the real vaporization enthalpy, a control experiment was conducted following a standard procedure from previous studies ^{7, 8}. Explicitly, PVA/PB samples with Φ 90 mm surface area and bulk water with the same exposure area (10 cm × 10 cm) were set in a container, together with the supersaturated potassium carbonate solution under a temperature of *c.a.* 20 °C and ambient air pressure. For the identical power input (U_{in}), the equivalent vaporization enthalpy of water in PVA/PB (ΔH_e) can be calculated through:

$$U_{in} = \Delta H_{vap} m_0 = \Delta H_e m_g \tag{S14}$$

Where ΔH_{vap} and m_0 are the evaporation enthalpy and mass change of bulk water, and m_g is the mass change of PVA/PB.

1.5 Measurement of water in PVA/PB

The total water content of the sample was obtained by thermal gravimetry (TGA, TGA/DCS3⁺, Mettler). Samples were first analyzed at 20 °C and heated to 250 °C at 5 °C min⁻¹. Differential scanning calorimetry (DSC, Diamond DSC, PerkinElmer, USA) was used to test and calculate the content of various species of water in the hydrogel. The sample pans were cooled to -40 °C and then heated to 40 °C at 5 °C min⁻¹. The area under the crystalline peak was measured, and the area under the exothermic or endothermic peak was measured, and the

amount of intermediated water was calculated from a calibration graph obtained by measuring the area under peaks produced by weighed samples of distilled water. All relevant enthalpy calculations were performed using Pyris software (version 10.1).

The melting behavior of PVA/PB was recorded by DSC to estimate the bound water content. The water fraction (W_{total}) of PVA/PB (mass ratio, PB *v.s.* PVA was 20 wt%), which is defined as ⁹:

$$W_{\text{total}}(\%) = 100\% - W_{\text{remain}}(\%)$$
 (S15)

where W_{total} represents the total water content in the sample, W_{remain} is the percentage of the remaining mass of the sample to the total mass. The DSC chart presents exothermic peaks that can be attributed to the crystallization of freezable water (including free water and intermediated water). Note that the bound water cannot form ice and hence will not present exothermic signals in DSC tests. The crystallizing enthalpy ΔH of supercooled water at a certain temperature (*T*) is ¹⁰:

$$\Delta H(T) = \Delta H(273) - \int_T^{273} \Delta C_p dT$$
(S16)

where $\Delta H(273)$ is the theoretical crystallizing enthalpy of pure water and ΔC_p is the difference of heat capacity between supercooled water and ice. The Eqution 16 is approximately expressed as the equation ¹¹:

$$\Delta H(T) = \Delta H(273) + 2.119 \cdot \Delta T - 0.00783 \cdot \Delta T^2$$
(S17)

where ΔT is the temperature difference between the freezing point of supercooled water (*T*) and the crystallizing temperature of ice (*T*₂₇₃). Therefore, the bound water content (*W*_{bound}) in PVA/PB can be estimated by the following equation ⁹:

$$W_{\text{bound}}(\%) = \left(1 - \left(\frac{\Delta H}{\Delta H(T) \times W_{\text{total}}}\right)\right) \times 100\%$$
(S18)

where ΔH is the heat flow calculated from the DSC measurement relevant to the crystal of water composed of intermediate water and free water.

Similarly, Eqution 17 can also be used for calculating the melting enthalpy ΔH of supercooled water with melting temperature *T*. The DSC spectra of PVA/PB in the range of form –40 to 20 °C was displayed in Figure 5c, one or two distinct endothermic peaks occurred in the melting stage related to the melting of ice. The DSC peak near 0 °C was caused by the melt of ice composed by free water, and the other DSC peak was caused by the melt of ice composed by intermediated water ^{11, 12}.

The weight fraction of free water (W_{free}) in PVA/PB can be estimated by the following equation ¹³:

$$W_{\rm free}(\%) = \frac{\Delta H_{\rm free}}{\Delta H(T)} \times 100\% \tag{S19}$$

where ΔH_{free} was the estimated value of heat flow caused by the melt of ice composed by or free water according to the integral are of DSC peaks near 0 °C (Figure 5d).

1.6 Water purification for contaminated water

A beaker contained 15 mL methyl orange, rhodamine B, rose Bengal, or methylene blue contaminated water (0.5 wt%) and a floated PVA/PB hydrogel was placed in a homemade steam condensation system. Upon simulated sunlight (1 kW m⁻²) irradiation, the condensed water was collected in a glass vial for further UV-Vis (UV-2600, Shimadzu, Japen) measurement. In addition, a standard solution containing 24 elements (aluminum, Al; arsenic, As; boron, B; barium, Ba; beryllium, Be; bismuth, Bi; cadmium, Cd; cobalt, Co; chromium, Cr; copper, Cu; iron, Fe; gallium, Ga; lithium, Li; magnesium, Mg; manganese, Mn; nickel, Ni; plumbum, Pb; antimony, Sb; stannum, Sn; strontium, Sr; titanium, Ti; thallium, Tl; vanadium, V; zinc, Zn)

was used to prepare simulated industrial polluted water with a concentration of 10 mg·mL⁻¹, and the water purification ability of the PVA/PB hydrogel was evaluated by ICP-AES (720-ES, Varian, USA).

1.7 Repellency of PVA/PB to bacterial and marine algae adhesion

Physical or biological settlement of marine bacteria upon the biomedical material surface promotes the following proliferation and inevitably causes the formation of the biofilm and decrease in evaporation rate of solar-vapor generators. Thus, it is vital to test the bacterialadhesion repellency that can minimize initial bacterial adhesion and eradicate biofilms if there are any. Four representative strains, which commonly exist in the marine environment, that is Gram-positive Bacillus subtills (B. subtills, CMCC 63501) and Enterococcus faecalis (E. faecalis, ATCC 29212), and Gram-negative Escherichia coli (E. coli, ATCC 25922), were obtained from the China General Microbiological Culture Collection Center. A monocolony of strains on a solid Luria-Bertani (LB) agar plate was transferred to 15 mL of liquid LB culture medium and cultured at 37 °C for 18 h to reach the log phase. Bacteria were harvested by centrifuging (3000 rpm) at 4 °C for 5 min and gently washed with phosphate-buffered saline (PBS, 0.1 mol L⁻¹, pH 7.2) three times, thereafter resuspending in 8 mL of PBS. The bacterial cells were diluted into 10^8 cells mL⁻¹ in PBS. Samples (1 cm \times 2 cm) were immersed in the adjusted cell suspensions (3 mL) in a 6-well plate. The plate was shaken at 37 °C for 6 h, followed by washing with PBS. The treated samples were washed with 1 mL of PBS to collect adherent bacterial cells removed from the surface of the respective samples. 40 µL of diluted bacteria were spread on a solid LB agar plate, and the colonies formed after 12 – 16 h incubating at 37 °C were counted. In addition, carbon cloth, nylon (NL66) films, and polyacrylamide

(PAAm) hydrogel were used as control groups. A minimum of three replication was performed for each material group to obtain a mean number and to ensure reproducibility ($n \ge 3$).

To further study the antifouling behavior of PVA, an initial inoculum of *Chlorella vulgaris* (*C. vulgaris*, FACHB-1) was obtained through the Freshwater Algae Culture Collection at the Institute of Hydrobiology. The *C. vulgaris* was pre-cultivated photo-autotrophically in sterile BG-11 media at a fixed temperature of 30 °C using a water-jacketed glass tube. The medium was continuously illuminated by a blank light LED (4 W). The *C. vulgaris* were diluted into 10^{6} cells mL⁻¹ in BG-11. Samples (1 cm × 2 cm) were immersed in the adjusted cell suspensions (3 mL) in a 6-well plate and shaken at 30 °C for 6 h. For SEM visualization, the samples were taken out of the above algae suspension and washed three times with sterile PBS. Then, algae were fixed in 4% paraformaldehyde for 15 min, followed by washing with sterile water and freeze-drying. Thereafter, samples sputtered with a thin conductive Au layer to avoid charging before being transferred into a high vacuum SEM chamber. The images were taken at an accelerating voltage of 10 kV and an accelerating current of 7 mA.

2. Figures and tables



Figure S1. SEM images of Prussian blue (PB).



Figure S2. Powder X-ray diffraction (PXRD) pattern of PB.



Figure S3. X-ray photoelectron spectroscopy (XPS) (a) survey spectra, (b) N 1s and (c) Fe 2p

peak-fitted curves of the PB nanocrystal.



Figure S4. Thermogravimetric analysis (TGA)/differential thermal analysis (DTA) curves of

PB nanocrystals.



Figure S5. Confocal microscopy images of the bionic vasculature PVA hydrogel.



Figure S6. Water evaporation rate in a dark condition of bulk water and vasculatural PVA/PB samples for different brine concentrations (n = 3).



Figure S7. Equivalent vaporization enthalpy of various brine concentrations in vasculatrual PVA/PB samples (n = 3).



Figure S8. Thermal gravimetric analysis image for PVA/PB hydrogels (mass ratio, PB vs. PVA

is 20 wt%) from 25 °C to 200 °C, the scanning speed is 5 °C min⁻¹.



Figure S9. Differential scanning calorimeter image from -40 °C to 40 °C for PVA/PB hydrogel exposed with various concentrations brine, the scanning speed is 5 °C min⁻¹.



Figure S10. Photothermal performance of the PBNCs- (PVA/PB) and carbon black-(PVA/CB) blended vasculatural PVA solar-driven-generator under 1 kW m⁻² solar simulator illumination.



Figure S11. PXRD pattern of PB irradiation at 3 Sun light for a period.



Figure S12. Fe element concentration of PB exposed with various brine for 100 d, insert diagram is working curve used for measurement.



Figure S13. Time-dependent photothermal performance of the various aerogels under (a) 1 kW m^{-2} , (b) 2 kW m^{-2} and (c) 3 kW m^{-2} solar simulator illumination.



Figure S14. Mass changes of PVA/PB-based SVGs in simulated (3.5 wt% brine) of various

samples as a function of sunlight irradiation time under 1 kW m^{-2} simulation solar light.



Figure S15. (a) SEM and (b–d) corresponding EDS mapping images of PVA/PB SVG serving for 10 h in 3.5 wt% NaCl.



Figure S16. Recycling performance of PVA/PB SVG.



Figure S17. Comparison of desalination performance between PVA/PB-based SVG and recently-reported SVGs.¹⁴⁻²³



Figure S18. Absorption spectra change of (a) methyl orange, (b) rhodamine B, (c) rose bengal, and (d) methylene blue contaminated water before and after purification by vasculatural

PVA/PB SVG.



Figure S19. Statistic number density of adhesion *B. subtilis*, *E. faecalis*, and *E. coli* on the coating sample counted through the plate counting method: (a) optical viable bacterial colony visualization and (b) corresponding statistical results (n = 3, ***p < 0.001).



Figure S20. SEM images of *C. vulgaris* attached to the samples in algae suspensions (c.a. 10^6 cells mL⁻¹) for 6 hrs.

Components	Luria-Bertani	LB-agar	BG-11
Agar	n/a	20	n/a
Ampicillin ($\mu g \cdot L^{-1}$)	n/a	n/a	50.0
$CaCl_2 \cdot 2H_2O$	n/a	n/a	0.036
Citric acid	n/a	n/a	6.0×10 ⁻³
Co(NO ₃) ₂ .6H ₂ O	n/a	n/a	0.0494
CuSO ₄ ·5H ₂ O	n/a	n/a	7.90×10^{-5}
Ferric citrate	n/a	n/a	6.0×10 ⁻³
H ₃ BO ₃	n/a	n/a	2.86×10 ⁻³
K ₂ HPO ₄	n/a	n/a	0.04
KBr	n/a	n/a	n/a
KC1	n/a	n/a	n/a
$MgCl_2$	n/a	n/a	n/a
$MgSO_4 \cdot 7H_2O$	n/a	n/a	0.75
$MnCl_2 \cdot 4H_2O$	n/a	n/a	1.81×10^{-3}
Na ₂ CO ₃	n/a	n/a	0.02
Na ₂ HPO ₄	n/a	n/a	n/a
Na ₂ MoO ₄	n/a	n/a	3.90×10 ⁻⁴
Na_2SO_4	n/a	n/a	n/a
NaCl	10.0	10.0	n/a
NaF	n/a	n/a	n/a
NaNO ₃	n/a	n/a	1.5
NH ₄ NO ₃	n/a	n/a	n/a
SrCl	n/a	n/a	n/a
Tryptone	10.0	10.0	n/a
Yeast extract	5.0	5.0	n/a
$ZnSO_4$	n/a	n/a	2.22×10^{-4}

Table S1. Chemical composition of culture media used in this work *

^{*}All concentrations in $g \cdot L^{-1}$ unless otherwise stated, and final pH had been adjusted to 7.2–7.4 at 25 °C.

References

- S. Liu, H. Yuan, H. Bai, P. Zhang, F. Lv, L. Liu, Z. Dai, J. Bao and S. Wang, J. Am. Chem. Soc., 2018, 140, 2284–2291.
- 2. D. Miao, X. Wang, J. Yu and B. Ding, *Adv. Funct. Mater.*, 2021, **31**, 2008705–2008715.
- 3. D. Quéré, Europhys. Lett., 1997, **39**, 533.
- 4. J. Szekely, A. Neumann and Y. Chuang, J. Colloid Interface Sci., 1971, 35, 273–278.
- 5. C. Li, H. Dai, C. Gao, T. Wang, Z. Dong and L. Jiang, *PANS*, 2019, **116**, 12704–12709.
- 6. C. D. Tsakiroglou and M. Fleury, *Transport in Porous Media*, 1999, **35**, 89–128.
- F. Zhao, X. Zhou, Y. Shi, X. Qian, M. Alexander, X. Zhao, S. Mendez, R. Yang, L. Qu and G. Yu, *Nat. Nanotechnol.*, 2018, 13, 489–495.
- G. Hu, Y. Cao, M. Huang, Q. Wu, K. Zhang, X. Lai, J. Tu, C. Tian, J. Liu and W. Huang, Energy Technology, 2020, 8, 1900721–1900730.
- W. Wang, P. P. Lu, Y. Fan, L. M. Tian, S. C. Niu, J. Zhao and L. Q. Ren, *Chem. Eng. J.*, 2019, **378**, 122173–122181.
- 10. T. Nakaoki and H. Yamashita, J. Mol. Struct., 2008, 875, 282–287.
- 11. Y. Hirata, Y. Miura and T. Nakagawa, J. Membr. Sci., 1999, 163, 357–366.
- 12. X. Zhou, Y. Guo, F. Zhao, W. Shi and G. Yu, *Adv. Mater.*, 2020, **32**, e2007012–e2007019.
- 13. H. Hatakeyama and T. Hatakeyama, *Thermochim. Acta*, 1998, **308**, 3–22.
- X. Han, W. Wang, K. Zuo, L. Chen, L. Yuan, J. Liang, Q. Li, P. M. Ajayan, Y. Zhao and J. Lou, *Nano Energy*, 2019, **60**, 567–575.
- Y. Liu, Z. Liu, Q. Huang, X. Liang, X. Zhou, H. Fu, Q. Wu, J. Zhang and W. Xie, J. Mater. Chem. A, 2019, 7, 2581–2588.
- X. Han, L. Zang, S. Zhang, T. Dou, L. Li, J. Yang, L. Sun, Y. Zhang and C. Wang, *RSC Adv.*, 2020, 10, 2507–2512.
- 17. J. Zeng, Q. Wang, Y. Shi, P. Liu and R. Chen, Adv. Energy Mater., 2019, 9, 1900552.
- 18. Y. Guo, F. Zhao, X. Zhou, Z. Chen and G. Yu, *Nano Lett.*, 2019, **19**, 2530–2536.
- X. M. Han, L. V. Besteiro, C. S. L. Koh, H. K. Lee, I. Y. Phang, G. C. Phan-Quang, J. Y. Ng, H. Y. F. Sim, C. L. Lay, A. Govorov and X. Y. Ling, *Adv. Funct. Mater.*, 2021, 31, 2008904–2008015.

- 20. Z. Huang, Y. H. Luo, W. Y. Geng, Y. Wan, S. Li and C. S. Lee, *Small Methods*, 2021, 1, 2100036–2100044.
- F. B. Zhu, L. Q. Wang, B. Demir, M. An, Z. L. Wu, J. Yin, R. Xiao, Q. Zheng and J. Qian, *Mater. Horiz.*, 2020, 7, 3187–3195.
- 22. M. Tan, J. Wang, W. Song, J. Fang and X. Zhang, *J. Mater. Chem. A*, 2019, **7**, 1244–1251.
- 23. X. Zhao and C. Liu, *Desalination*, 2020, **482**, 114385–114392.