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Lignocellulose based hydrogel sponge for cost-effective seawater desalination

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ABSTRACT——Currently, freshwater scarcity is becoming an increasingly pressing issue worldwide. Solar desalination technology is recognized as a promising solution to this problem. However, the existing seawater desalination evaporators suffer from slow evaporation rates and limited salt tolerance. To address this, we developed a lignocellulosic hydrogel sponge (LHS) using a straightforward salting-out method. This hydrogel sponge achieves a high evaporation efficiency of 2.57 $kg\cdot m^{-2}\cdot h^{-1}$ and exhibits excellent salt, acid, and alkali resistance. Therefore, LHS presents a new approach for solar-driven water purification, which holds significant implications for solving freshwater scarcity.

1.Introduction

The shortage of freshwater resources worldwide poses a significant threat to the survival and social development of every country. To address this problem, a simple, efficient, low-cost, and green seawater desalination technology is needed[1]. To date, more than 20 seawater desalination technologies have been developed, and the emergence of solar-driven interfacial evaporation technology provides a scalable green economic solution for seawater desalination[2,3]. So far, various photothermal conversion materials have been developed to achieve solar-driven steam generation, such as plasmonic materials, semiconductor materials, and carbon-based materials[4,5]. However, most of the reported photothermal conversion materials are expensive and have complex manufacturing processes[6]. In this work, we designed a green and eco-friendly lignocellulose hydrogel sponge solar-driven evaporator, which is composed of lignocellulose for efficient photothermal conversion, PVA hydrogel for water transfer, and polyurethane sponge for mechanical support. The hydrophilic PVA hydrogel can rapidly transfer water, leading to enough saltwater being transferred from bulk water to the evaporator surface, which plays a role in controlling the over-saturation of the evaporating liquid and suppressing salt crystallization, thereby improving the evaporation efficiency. Therefore, the lignocellulose hydrogel sponge exhibits high evaporation efficiency and excellent solar steam generation efficiency under a single solar irradiation. Moreover, the designed evaporator shows excellent salt accumulation resistance, good stability, and durability in continuous solar desalination tests with a 3.5% NaCl solution, providing a new method for seawater desalination.

2.Experimental section

2.1.Materials

Poplar powder with less than 100 mesh is used as raw material. Choline chloride ($C_5H_{14}ClNO$, >98%) and oxalic acid dihydrate ($H_2C_2O_4$ 2H2O, >99%) were purchased from Shanghai Macklin Biochemical Co., Ltd. Poly (vinyl alcohol) (PVA, 99%) was was acquired from Shanghai Aladdin Bio-Chem Technol-ogy Co., Sodium citrate dihydrate($C_6H_5Na_3O_7\cdot 2H_2O$, 99.0 %) was obtained from Shanghai Aladdin Bio-Chem Technology Co. sodium chloride (NaCl, AR) was taken from Sinopharm Chemical Production reagent Co., LTD,.

2.2.Preparation of lignocellulose

A transparent deep eutectic solvent (DES) solution was prepared by mixing 25.214 g of oxalic acid dihydrate and 27.924 g of choline chloride, and heating and stirring the mixture at 80℃. Subsequently, 5.3138 g of poplar wood powder was added into the aforementioned DES solution, and heated at 110 ℃ for 11 hours to obtain the lignocellulose.

2.3.Preparation of LHS

Cutting polyurethane foam into 1cm × 1cm × 1cm cubes, soaking them in ethanol and ultrasonically cleaning them for 30 minutes, is the first step in this experiment. Next, 1g of lignocellulose is weighed and added to a beaker containing 10ml of 5 wt% PVA solution. The mixture is stirred until homogeneous. The dried polyurethane foam is then thoroughly soaked in the above solution. The soaked foam is frozen at -40℃ for 3

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hours. Finally, the resulting sample is immersed in a 5.8g/10ml sodium citrate solution for 24 hours to obtain LHS.

2.4.Characterization

Test the contact angle using a JY-82 Contact Angle Apparatus (Chengde Dingsheng Company, Ltd., China).The mechanical properties of the samples were tested using a microcomputer tensile testing machine (Xiamen Senbei Technology Co., Ltd., China).

2.5.Solar steam generation measurements

The evaporative performance of the samples was tested using a solar simulator (PLS-SXE300, Beijing Perfectlight) to simulate light conditions. The light intensity was adjusted using a light power meter (PL-MW2000, Beijing Perfectlight). During the test, the change in mass was recorded using an electronic microbalance with an accuracy of 0.1 mg. In addition, the surface temperature of the samples was measured using an infrared spectrophotometer (IR camera, FLUKE TiS20+).

3.Result and discussions

3.1.Wettability of LHS

In order to evaluate the surface wettability of polyurethane foam and lignocellulose hydrogel foam, the contact angles of water on PS and LHS were measured in air. As shown in Figure 1a1-a3, the polyurethane foam exhibited hydrophobicity with a water contact angle of 120° in air. In contrast, the modified LHS demonstrated excellent water absorption performance, as water droplets were immediately absorbed upon contact with the surface of LHS (Figure 1b1-b3). This is due to the presence of a large number of hydroxyl groups in the PVA molecules, which exhibit hydrophilic properties and can attract and retain water molecules.

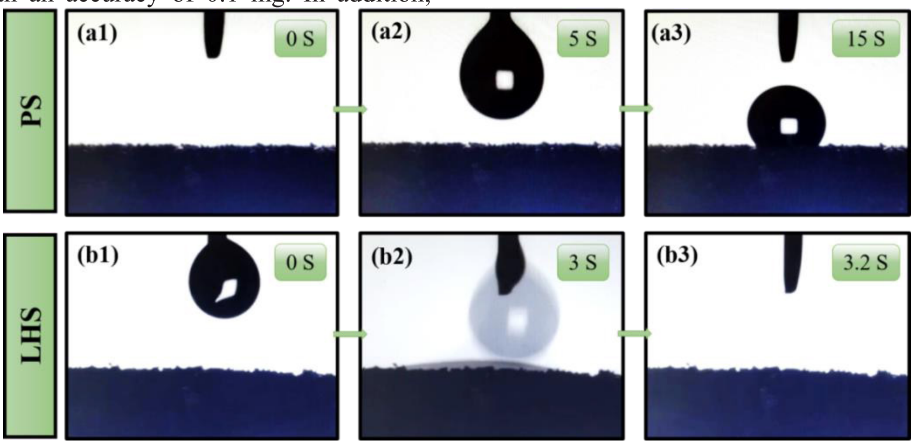

Figure 1. (a1-a3) Water contact angle of polyurethane sponge in air. (b1-b3) Water contact angle of lignocellulose hydrogel sponge in air.

3.2.Solar desalination test

Using a xenon lamp light source to simulate solar irradiation, the surface temperature of LHS was measured using an infrared camera under a solar irradiation. Figures 2a1-a6 show the variation in surface temperature of LHS, which increases with time and can reach up to 27.7℃. This indicates that LHS can elevate the surface temperature of the evaporator by absorbing solar energy, which promotes water evaporation and enhances the evaporative performance of the evaporator. Figure 2b depicts the seawater evaporation process of LHS with different PVA concentrations under solar irradiation. Figure 2c shows the evaporation efficiency of LHS with different PVA concentrations. It is observed that as the PVA concentration increases, the evaporation efficiency increases from 1.984 $kg \cdot m^{-2} \cdot h^{-1}$ to 2.57 $kg \cdot m^{-2} \cdot h^{-1}$, which may be attributed to the higher concentration of PVA leading to more PVA molecules binding with water molecules, thus increasing the adhesion between water molecules and facilitating their evaporation. In summary, the lignocellulose hydrogel sponge demonstrates efficient evaporative performance.

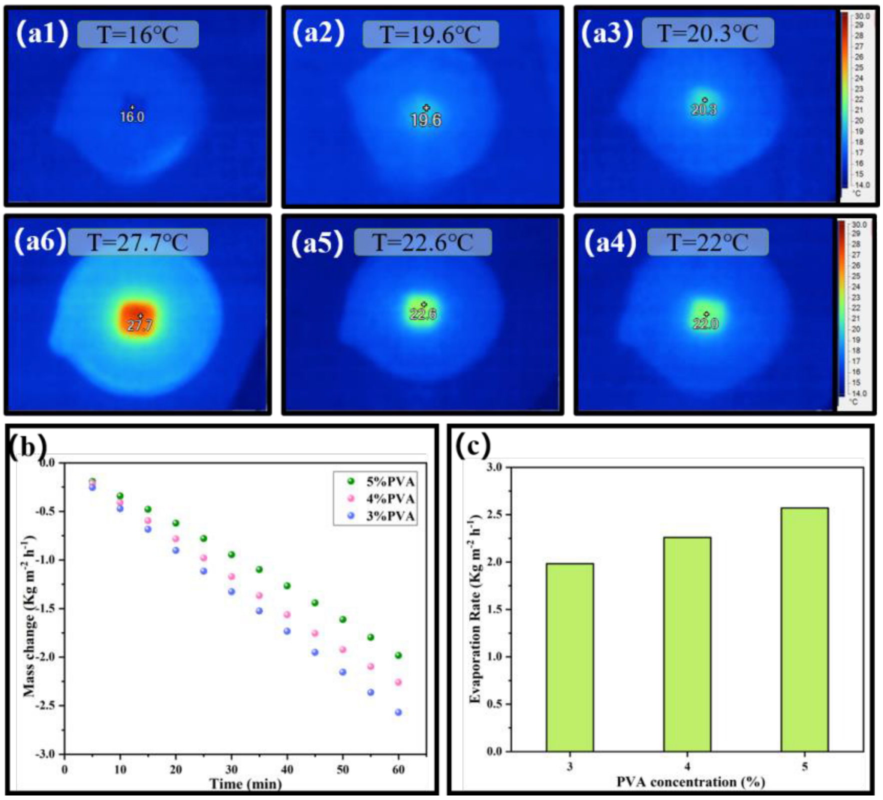

Figure 2. (a1-a3) Infrared photo of LHS under a solar light irradiation.(b) Mass change of water gel sponges prepared with different PVA concentrations under a solar irradiation intensity. (c) Evaporation rate of water-absorbent hydrogels with different PVA concentrations.

3.3.Durability test

In order to ensure stable operation of the solar evaporator in the constantly changing environment, the prepared materials should have good stability to ensure their long-term use. This article mainly analyzes the stability of the wood-based cellulose hydrogel sponge from the aspects of salt resistance, acid and alkali resistance, and mechanical properties. In the solar evaporator, water is usually polluted by salt from natural water sources or seawater. These salts will accumulate and remain on the surface of the evaporator, leading to a decline in its performance. Therefore, salt resistance is one of the important factors for the stable and durable performance of the solar evaporator. To demonstrate the salt resistance of the LHS, 2.5g NaCl was scattered on the surface of the evaporator. As shown in Figure 3a1-a6, most of the salt dissolved after 30 minutes. This is because the hydrogel sponge surface contains a large number of hydroxyl groups with hydrophilic properties, which can promote the dissolution of salt molecules. After 60 minutes, all the salt dissolved on the surface of the hydrogel sponge, indicating that the LHS exhibited good self-cleaning properties.

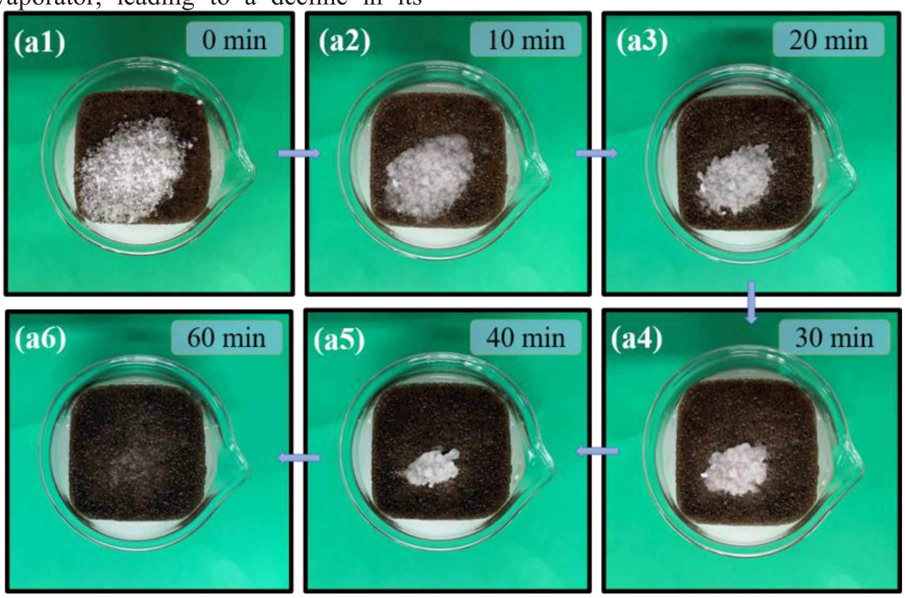

Figure 3. (a1-a6) Salt resistance of LHS with 2.5 g NaCl on the surface

To evaluate whether LHS is suitable for complex and harsh environments, the prepared LHS was immersed in acid-base solutions (pH=1-13). Figure 4 a1-a2 shows that after seven days of immersion in the acid-base solution, the state of LHS has remained essentially unchanged. This indicates that LHS can maintain stability in acidic and alkaline environments. The mechanical performance of the sponge was tested as shown in Figure 4b, and the compressive stress-strain curve was found to have only minor differences after 20 cycles. The required compressive stress did not show significant changes until the compressive strain was below approximately 400%. However, when the compressive strain exceeded 400%, the compressive stress increased significantly. This superior mechanical performance of the left-hand side (LHS) sponge can be attributed to the addition of polyvinyl alcohol (PVA) for salting-out, which can form a three-dimensional porous hydrogel and simultaneously enhance the mechanical strength of the hydrogel.

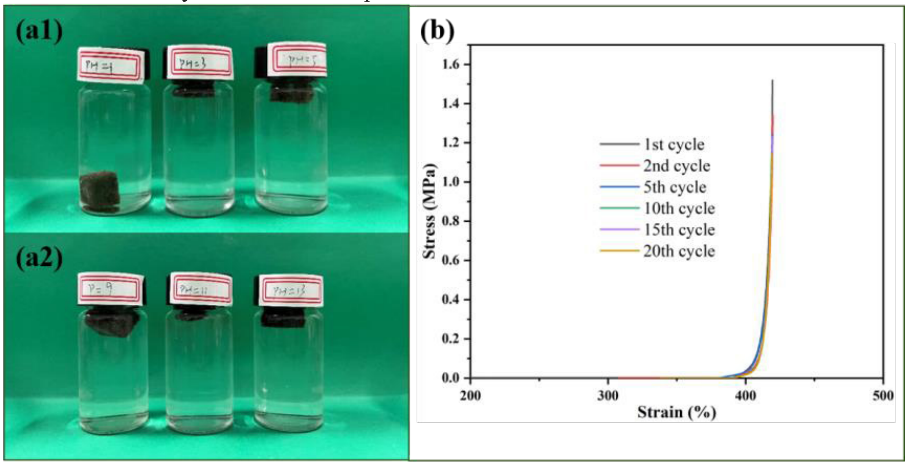

Figure 4. (a1-a2) Stability test of LHS under acid and alkali conditions for seven days. (b) Stress-strain curve of CLH extrusion for 20 times.

4.Conclusion

In summary, we report a salt-assisted strategy for the preparation of a lignocellulose hydrogel sponge-based solar-driven evaporator for efficient and economical solar desalination. The lignocellulose hydrogel sponge exhibits high evaporation efficiency of 2.57Kgm-2h-1, good thermal localization effect, and excellent salt resistance. Meanwhile, the preparation of LHS selects low-cost poplar wood powder, and the preparation process is environmentally friendly. In addition, the size of the hydrogel sponge can be flexibly controlled, which has important practical significance.

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