Preparation of flower-like hydrogel and its application in sea water desalination

Jingkang Fang[a*], Mengsheng Xia, Yule Li, Junkai Gao

School of Ships and Maritime Transport, Zhejiang Ocean University, Zhoushan, Zhejiang Province, 316022, China

Abstract—The situation of global water crisis is becoming more and more serious[1]. Due to the inconvenience of fresh water carrying or long-term storage and deterioration, the personnel and equipment of oceangoing ships are in urgent need of fresh water resources[2]. However, the traditional seawater desalination technology will consume fossil energy or its economy is not high. Under the background of a series of green ship development plans, people focus on green clean energy to solve the problem of fresh water shortage[3]. Interfacial photoevaporation is an effective strategy to promote seawater desalination and pollutant treatment. Photothermal conversion materials and evaporators have shown their good performance in improving seawater desalination efficiency. In this paper, the photohot water gel prepared by calcium chloride, polyvinyl alcohol, sodium citrate, tannic acid and ferric chloride was used as the photothermal conversion material[4]. The properties of photoevaporative seawater desalination materials were studied by a series of instruments such as optical microscope and contact Angle measuring instrument. The experimental results show that the flower-like hydrogel has high photothermal conversion efficiency and has a good application prospect in green Marine desalination field.

1. Introduction

Since the 21st century, with the rapid increase of global population, the large-scale development of industry and the rapid development of the economy, the demand for water resources in society has also risen sharply[5]. In addition, the protection of water resources in various countries is not enough. A large part of fresh water is polluted so that it cannot be used normally, so there is a shortage of fresh water in all regions. For the shipping industry, this problem is more prominent. As an independent unit, the ship cuts off the channel of fresh water supply after leaving the land. However, fresh water is necessary for the ship 's equipment and crew 's life. The oceangoing ship itself carries a large amount of fresh water, which will not only reduce the ship 's loading capacity and increase energy consumption. At the same time, the long-term placement of fresh water in the fresh water tank will cause problems such as bacterial growth and water quality deterioration, which cannot meet the crew 's drinking standards[6]. In general, the crew needs to replenish 5L of fresh water per person per day. For general large ships, about 200 tons of fresh water are needed every day. In order to solve the problem of lack of fresh water resources in ships, seawater desalination is considered to be the most ideal method.

In the past few decades, many photothermal conversion materials have been designed for the field of solar-driven interfacial evaporation (SDIE)[7]. Common materials include biomass materials, carbon-based solar energy absorption materials, and nano-metal materials. The heat is concentrated at the junction of water and air, reducing the consumption of heat propagation in water, and achieving efficient photothermal-steam conversion. Interface evaporation technology is widely used in the field of seawater desalination because of its advantages of high efficiency, cleanliness and no secondary pollution.

[a*]fjk199906@163.com

This paper intends to prepare flower-like hydrogels for seawater desalination, characterize their material morphology, and study their photothermal conversion efficiency and salt resistance. Flower-like hydrogel is a low-cost and environmentally friendly photothermal material, which will be widely used in the field of marine seawater desalination in the future[8].

2. Experimental method

2.1. Preparation of flower-like hydrogel

As shown in Figure 1：At room temperature, calcium chloride 5.6g, polyvinyl alcohol 5g, dissolved in 95ml of water, mixed solution in a magnetic stirrer (10kr / min) under continuous mixing fully mixed. After stirring for a period of time, the collector constant temperature heater is heated to above 95 °C for 30 min. The heated solution was sonicated in an ultrasonic cleaner for 30 min, and 8ml solution was poured into a petri dish and frozen in a refrigerator. After freezing, 5ml of 37 % sodium citrate solution was added, and then the prepared hydrogel was immersed in 3 % tannic acid, and finally poured into 5 % ferric chloride solution to make a flower-like hydrogel.

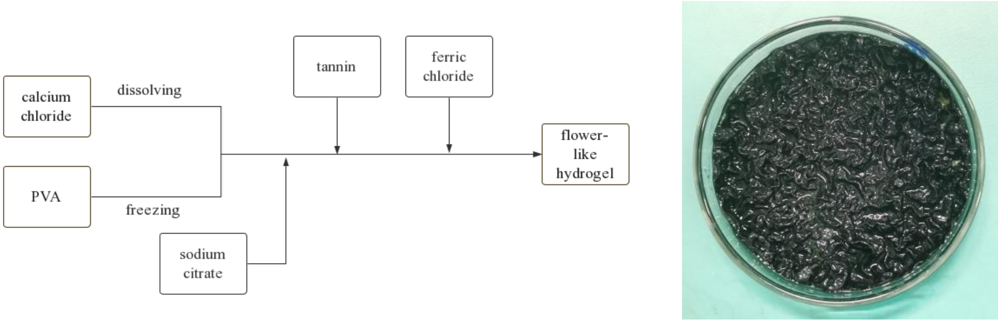

Fig. 1**.**Preparation process of tea powder-PVDF membrane.

2.2. Material Characterization

The material morphology was characterized and analyzed by field emission scanning electron microscope (JSM-6700F, JEOL). The contact angle was measured with an optical contact angle meter (POWEREACH JC200D2, China).

2.3. Sea water desalination

The sea water desalting device(Fig. 2)Uses a solar xenon lamp and an electronic scalesXenon lamp (PLS-SXE300 +) was used to simulate sunlight. In order to ensure that the liquid level height of each test was the same, 500ml distilled water was filled into a glass beaker, and the light intensity of the xenon lamp was adjusted to 1 kW m^{-2} by using a full-spectrum optical power meter, that is, 1 solar intensity. The glass beaker is placed on a precision balance, and the position is adjusted so that the simulated sunlight is vertically irradiated on the surface of the evaporating material. The mass change during evaporation is recorded, and the surface temperature change of the evaporating material during evaporation is recorded by an infrared imager. After opening the light source, the photothermal test can be started, and the data are recorded every 5 minutes.

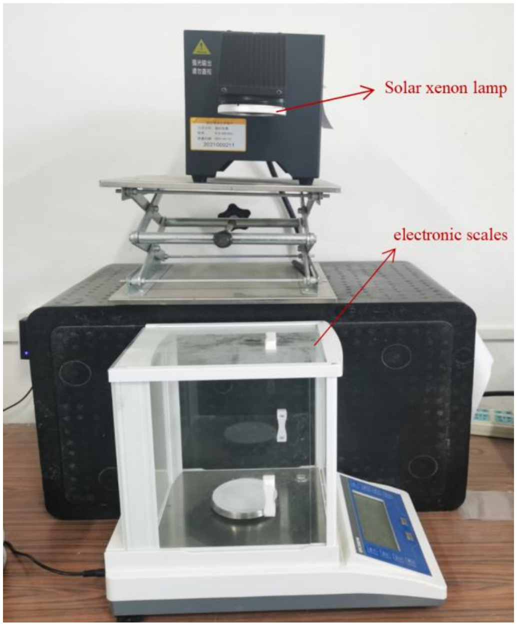

Fig. 2**.**The sea water desalting device.

3. Results and Discussion

3.1 .Structural characterization

3.1.1. Determination of hydrophilic angle

The contact angle refers to the angle θ between the tangent of the gas-liquid interface and the solid-liquid interface at the junction of the gas, liquid and solid phases[9]. It is an index to measure the wettability of the material. In the process of solar water evaporation, hydrophilicity is a very critical factor, we can use the contact angle to study its hydrophilic properties. When a small drop of water is added to the surface of the flower-like hydrogel, the material can quickly absorb water within 0.2 seconds, and the contact angle θ is extremely low, almost close to 0, indicating that the flower-like hydrogel is superhydrophilic and has excellent water permeability[10]. Therefore, sufficient water can be provided during the water evaporation process to ensure that the water evaporation process continues.

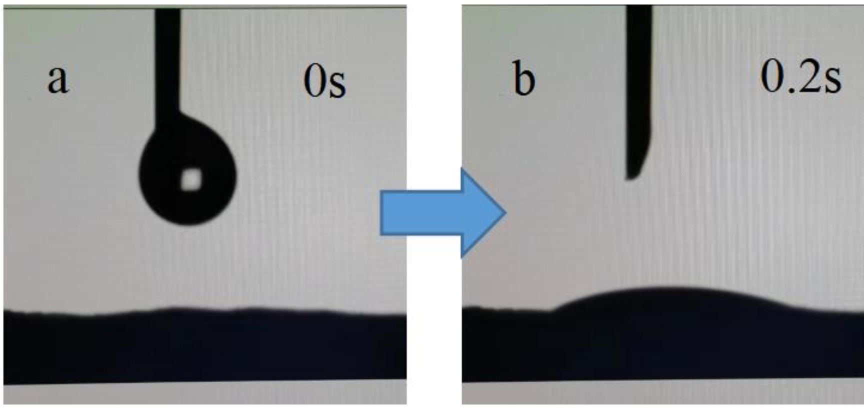

Fig. 3.（a）The hydrophilic angle at 0 seconds；（b）The hydrophilic angle at 0.2 seconds；

3.1.2. Desalting property

The salt self-cleaning ability test after adding additional salt to the evaporated surface placed 3 grams of additional salt crystals directly on the top of the hydrogel surface. After contact with water, the solid NaCl on the evaporation surface begins to dissolve, which is due to the movement and exchange of the solution in the absorption layer and the transport of a large amount of water connecting the evaporation surface with the thermal insulation layer. After about 60 minutes, the evaporation device completely removed the additional salt, indicating its good salt removal capacity.

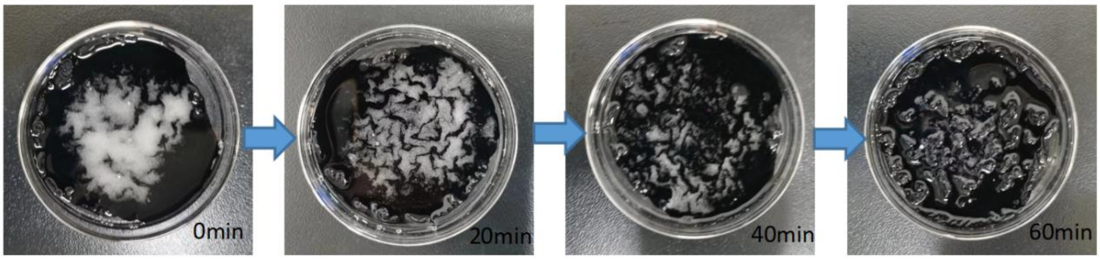

Fig. 4.Dissolution of salt crystals on the surface of hydrogel over time

3.2. Desalination efficiency

Xenon lamp (PLS-SXE300 +) was used as a light source to simulate solar evaporation. The sponge was trimmed according to the size of the flower-like hydrogel so that it can wrap the hydrogel and can be placed in a beaker. Then the sample was placed in a beaker containing distilled water and irradiated for 1 hour under a light intensity of 1 kw m^{-2}, that is, a solar light intensity. The mass change on the balance was recorded. According to the evaporation rate calculation formula. Where v is the evaporation rate of water ; m is the quality of water reduction, that is, the quality of steam ; s is the sample area ; t is the illumination time. The water evaporation rate of the photothermal material is calculated to be 1.50 kg m^{-2} h^{-1}.

4 .Conclusion

The flower-like hydrogel prepared from calcium chloride, polyvinyl alcohol, tannic acid, ferric chloride and sodium citrate has high photothermal conversion efficiency and strong light absorption performance. The water evaporation rate in the laboratory can reach 1.50 kg m^{-2} h^{-1}. By exploring the wettability of the hydrogel evaporator, it was found that it had high water absorption and was a hydrophilic material, which could continuously transport water during water evaporation. The hydrogel evaporator was tested for salt self-cleaning ability. The material can completely exclude the additional salt added, indicating its good salt exclusion ability.

References

1. Chen Y, Fang J, Ling T, et al. Bamboo shoot-based evaporator with self-cleaning and mildew-resistant for efficient solar steam generation[J]. Desalination, 2022, 541: 116003.
2. Bairagi U, Jacob J. Regenerative macroporous polyzwitterionic gels for brackish/sea water desalination[J]. Desalination, 2022, 535: 115801.
3. Bai X, Hou Y, Yang D. Choose clean energy or green technology? Empirical evidence from global ships[J]. Transportation Research Part E: Logistics and Transportation Review, 2021, 151: 102364.
4. Su X, Hao D, Sun M, et al. Nature sunflower stalk pith with zwitterionic hydrogel coating for highly efficient and sustainable solar evaporation[J]. Advanced Functional Materials, 2022, 32(6): 2108135.
5. Zou Y, Yang P, Yang L, et al. Boosting solar steam generation by photothermal enhanced polydopamine/wood composites[J]. Polymer, 2021, 217: 123464.
6. Xia Y, Hou Q, Jubaer H, et al. Spatially isolating salt crystallisation from water evaporation for continuous solar steam generation and salt

harvesting[J]. Energy & Environmental Science, 2019, 12(6): 1840-1847.

7. Wu S, Jian R, Tian S, et al. Simultaneous solar-driven seawater desalination and continuous oil recovery[J]. Nano Energy, 2023, 107: 108160.
8. He J, Ge J, Pang Y, et al. A 3D Corncob-based interfacial solar evaporator enhanced by environment energy with salt-rejecting and anti-corrosion for seawater distillation[J]. Solar Energy, 2023, 252: 39-49.
9. Bairagi U, Jacob J. Regenerative macroporous polyzwitterionic gels for brackish/sea water desalination[J]. Desalination, 2022, 535: 115801.
10. Cao Y, Zhu X, Ni Z, et al. Construction of PVA hydrogel-based solar-driven interfacial distillation device and its performance research in selective adsorption of organic solvents and removal of Rh B[J]. Separation and Purification Technology, 2022, 295: 121274.