3D toilet-paper based carbon fiber for excellent solar assisted steam generation performance

Xidong Suo (xidsuo@126.com)  
Xinzhou Normal University  
Yao Li  
Xinzhou Normal University  
Peiqi Liu  
Xinzhou Normal University  
Yingying Li  
Xinzhou Normal University  
Cuirong Guo  
Xinzhou Normal University  
Jie Yang  
Xinzhou Normal University  
Hongtao Qiao  
Xinzhou Normal University  
Sheng Han  
Shanghai Institute of Technology  
Chenqi Liu  
Xinzhou Normal University  
Aiping Yin  
Xinzhou Normal University

Research Article

Keywords: 3D solar steam generation, toilet paper, porous carbon materials, carbon fiber

Posted Date: July 13th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3137686/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Abstract

As a promising technology, interfacial solar steam technology has been widely recognized as an effective way to solve the shortage of energy and water, especially in remote areas. Whole roll of toilet paper (TP) is composed of well orderly layer-by-layer paper which consisted by cellulose fiber. Here, a 3D solar steam generator which is prepared by carbonized TP with the help of high temperature carbonization and NaOH activated under inert atmosphere is firstly demonstrated with excellent fresh water production capacity. Thanks to the good ordered layered structure which consisted by porous carbon fiber, the evaporation speed of obtained evaporator is up to 3.37 kg m\(^{-2}\) h\(^{-1}\) under one sun (1000 W m\(^{-2}\)) in laboratory, and the average value of 20.4 kg m\(^{-2}\) day\(^{-1}\) in a 20 consecutive days outdoor experiment for treatment of stimulate sea water, respectively. The demonstrated 3D evaporator for per square meter can meet the drinking water demand of more than 10 people. This work opens a promising approach for utilizing unique structure of commercialized available artificial materials and technologies to produce fresh water from seawater.

Introduction

With the rapid increasement of economy and world population, the conflict between demand and supply for fresh water and energy tend to rise, specifically in remote districts and sea voyage\([1, 2]\). Additionally, many populations in cities are threatened by a drinking-water shortage\([1, 3, 4]\). Solar assistant interface evaporation, where only solar energy input rather than electricity or fossil-based energy, is considered as the most economical technology to produce drinkable water from polluted and sea water to ease global water shortages\([5–7]\). Compared to numerous other available technologies, such as adsorbed treatment\([8–10]\), reverse systems\([11, 12]\), multi-stage flash\([13, 14]\), tiny-fog collection\([15–17]\) and traditional solar assistant bulk water heating steam generation\([18]\), solar assistant interface evaporation technology can efficiently produce drinkable water owing to its excellent light trapping performance, unique interfacial localization way for energy utilization and an appropriate water supply system\([19]\). It is widely regarded that the sunlight trapping and photothermal conversion materials play a key role in solar interfacial evaporation systems\([20, 21]\). A large number of artificial materials have been proposed for purifying the seawater and polluted water and attempting to provide drinking water, such as noble metal nanoparticles\([22–24]\), carbon nanotube\([25, 26]\), graphene oxide or reduced graphene oxide\([27–29]\). However, the high cost, complex manufacture process and water evaporation rate of the photothermal conversion materials severely impede its popularization and utilization.

Delightedly, many three-dimensional (3D) evaporators have been developed to enhance the water evaporative performance and biobased photothermal materials were introduced to cut the costs\([30, 31]\). Generally, 3D evaporator possesses a larger surface for absorbing the energy from the surroundings, which make its greater evaporation performance than that of most traditional 2D evaporator\([32–34]\). Over the past few years, especially biobased 3D evaporator shows huge advantages in solar assistant steam generation. The biggest advantage of the 3D evaporator is that its evaporation rate greatly exceeds the theoretical value (1.47 kg m\(^{-2}\) h\(^{-1}\)) under one sun illumination\([32, 35]\). For instance, a 3D cup-
shaped evaporator was fabricated by carbonized sorghum straw at the temperature of 400 °C with the evaporation rate of 3.27 kg m\(^{-2}\) h\(^{-1}\) under one sun\(^{[32]}\). A corncob based 3D evaporator exhibited a steady evaporation rate of 4.16 kg m\(^{-2}\) h\(^{-1}\), where corncob was carbonized at 450 °C and activated by NaOH\(^{[36]}\). Additionally, a poly (methyl methacrylate) (PMMA) based 3D evaporator also exhibits good evaporation performance under one sun (3.6 kg m\(^{-2}\) h\(^{-1}\))\(^{[37]}\). Although the evaporation performance of some 3D evaporators has improved largely, it is also essential to explore new evaporators with the merit of environmentally friendly, low-cost and easy to industrialize for meeting the various needs of the market and raw material sources.

In this manuscript, we firstly report that carbonized toilet paper (CTP) can act as an outstanding 3D evaporator owing to its unique vertical layer-by-layer structure. Obtained evaporator exhibits excellent fresh water production capacity from stimulated seawater, especially in outdoor experiments. The solar steam evaporator based on TP shows a water evaporation speed as high as 3.37 kg m\(^{-2}\) h\(^{-1}\) under one sun, and the average value of 20.4 kg m\(^{-2}\) day\(^{-1}\) in a 20 consecutive days outdoor experiment for treatment of stimulate sea water, respectively. As the commercial products, TP shows greatly potentials for large-scaled preparation of solar driven evaporator due to its unique artificial layer-by-layer structure, low cost, and renewable raw materials.

**Experimental section**

**Materials and Chemicals**

Toilet paper (TP) was purchased from a local supermarket (Bupai, Shanxi Jilong Yuan Trading Co., Ltd, China). Phenol-formaldehyde resin (PF), N,N-dimethylformamide (DMF) was got from Aladdin (Shanghai, China). NaOH and KOH purchased from Tianjin Fengchuan Chemical Reagent CO., Ltd (Tianjin, China). H\(_3\)PO\(_4\) was got from Tianjin Shentai Chemical Reagent Co., Ltd (Tianjin, China). CuCl\(_2\) and ZnCl\(_2\) were got from Aladdin (Shanghai, China).

**Fabrication steps of the TP based evaporators**

PF was dissolved in DMF with the solid concentration of 20 wt %. The whole roll of TPs with the diameter of about 4 cm were dried in the oven at 105 °C for 12 h to remove the adsorbed moisture. The obtained TPs were immersed into 10 wt % PF solution for 10 h at 30 °C in a vacuum oven (-0.08 ~ -0.1 MPa) for totally soaked by PF, and then putted resulting samples (phenol-formaldehyde resin modified TP, FTPs) in an oven at 105 °C for 24 h to remove the residual solvent. The obtained FTPs were carbonized at 800 °C for 2h under the N\(_2\) atmosphere, and then activated at 800 °C for 2 h after immersed into activated agent solutions (NaOH, KOH, H\(_3\)PO\(_4\), CuCl\(_2\) and ZnCl\(_2\)). The as-prepared evaporators were washed by deionized water to remove the residual chemicals, and dried in oven at 60°C for 24 h. The resulting evaporators were named as CFTP, Na- CFTP, K- CFTP, P- CFTP, Cu- CFTP and Zn- CFTP, represented as TP based evaporators no-activated by chemicals and only activated by NaOH, KOH, H\(_3\)PO\(_4\), CuCl\(_2\) and ZnCl\(_2\) respectively.
Characterizations

A Zeiss Sigma 300 SEM (German) were employed to investigate the surface and microstructure of the TP based evaporators with the help of gold sputter coating. Light absorption spectrum of the TP based evaporator were surveyed by a UV-visible Spectrometer (Lambda1050, Germany). A contact angle meter was used to evaluate the hydrophilic performance of the evaporators. The K\(^+\), Na\(^+\), Ca\(^{2+}\), Mg\(^{2+}\) contents of before and after treated water were tested using an ICP equipment (Agilent 5110, America).

Solar evaporation experiment

Mass change of the TP resulting evaporator were record by a computer controlled electronic balance with a Xenon lamp (assembled an AM 1.5 light, PLS-SXE300 China) illuminated. FZ-A power meter (China) was employed to measure the light intensity of the Xenon lamp and sun light. For evaluating the evaporation performance of the TP based evaporator, all samples were placed on a PS foam which wrapped with cotton cloth, where PS foam acted as a heat insulation between bulk water and work face. The temperature of the evaporators was recorded by a infrared camera (ST9450, China).

Results and Discussion

TP based evaporators

Figure 1a exhibits the manufacturing process and the layer-to-layer structure of the toilet paper (TP) based evaporators. First, raw TP is immersed in phenol-formaldehyde resin (PF) and chemical agent in turn after dried in a vacuum drying oven at 105 °C for removing the residual solvent. Second, the resulting samples are carbonized at 800 °C for 2h under the N\(_2\) atmosphere. Third, carbonized samples are washed three times by distilled water for removing the residual impurity and ash. Last, prepared 3D evaporator samples are assembled into a homemade device for testing the evaporation performance. Owing to the critical layer-by-layer structure which consisted by carbonized porous fiber (Fig. 1b), the water and saline water can be easily transported to the top and side surface for evaporation; meanwhile, sunlight can be well captured by carbonized paper fiber, expressly by rich porous structure on the whole fiber body. The vertical layers of structure and the intrinsic porous carbonized paper fiber will achieve a much improved water steam generation performance.

The resulting samples are named as CFTP, Na- CFTP, K- CFTP, P- CFTP, Cu- CFTP and Zn- CFTP, represented as TP based 3D evaporators TP modified by FP but without activated by any chemicals, and activated by NaOH, KOH, H\(_3\)PO\(_4\), CuCl\(_2\) and ZnCl\(_2\) respectively. Here, direct carbonized TP (CTP) is taken as a blank sample. As shown in Fig. 2a, raw TP exhibits highly ordered layer-by-layer structures which is constituted by micro paper fiber. However, the ordered layer-by-layer structures are destroyed and become disorderly texture structure (Fig. 2b) after directly high temperature pyrolysis; howbeit, the layer-by-layer structure are well maintained (Fig. 2c) under the same pyrolysis process after raw TP modified by PF. Additionally, the mechanical properties of the TP based evaporator have been largely improved after
immersed by PF. As exhibited by Fig. 2d, the mechanical property of TP based carbon materials are improved largely after immersed by PF. Excellent mechanical properties are a prerequisite for durable and stable performance of TP based water evaporator.

As exhibited in Fig. 3, the sample CTP show a typical fiber structure coated by many grooves on the surface. After activated by NaOH, the carbonized TP exhibit numerous micropores on the carbon fiber skeleton (Fig. 3c), which would further improve the surface roughness and increase the capability of light capture. In contrast, TP activated by other chemical agents does not exhibit obvious porous feature as shown in Figure S2-3 in the Supporting Information. From the SEM results, the NaOH-activated process is more impactful to enhance the porosity and roughness for the surface of TP based carbon fiber. To investigate more detail porous information, the BET was employed to get the porosity of the different chemical agent treated samples. As exhibited in Fig. 4a and Figure S4 in the Supporting Information, Na-CFTP show remarkably abrupt N$_2$ uptake at a low relative pressure (P/P$_0$) and this curve is interrelated with the characteristic of type , which is typical for activated carbon materials, indicating a better micro-mesopore forming ability of the NaOH than other chemical activated reagents in this case. The main pore size distribution of the Na-CFTP is from 1.7 nm to 20 nm as shown in Fig. 4b. As exhibited in Table S1 in the Supporting Information, the BET surface area of Na-CFTP is as high as 1164.1 m$^2$ g$^{-1}$ which is largely higher than those of CTP (178.8 m$^2$ g$^{-1}$), CFTP (91.9 m$^2$ g$^{-1}$), K-CFTP (1.9 m$^2$ g$^{-1}$), P-CFTP (7.6 m$^2$ g$^{-1}$), Cu-CFTP (1.3 m$^2$ g$^{-1}$) and Zn-CFTP (1.8 m$^2$ g$^{-1}$). The BET results agree very well with the SEM results and good porous structure would have more space to capture the light when the evaporator under the sun.

Good light capture capability is a prerequisite for efficient evaporation. As exhibited in Fig. 4c and Figure S5 in the Supporting information, the CTP could only absorb 84.7% incident light in the range of 250–2500 nm. Among other five carbonized samples, the Na-CRTP shows the best light absorb performance with the 90.9% absorptivity in the entire solar spectrum, which is obviously higher than those of other treatment process samples. Additionally, good hydrophilicity is essential to achieve high efficiency solar driven evaporation to 3D evaporator, which can supply enough water to evaporator for evaporation. As illustrated in Fig. 4e and Figure S6 in the Supporting Information, after activated by chemical agents (NaOH, KOH, H$_3$PO$_4$, CuCl$_2$), the corresponding evaporators exhibit excellent hydrophilicity and which water droplets instantly and fully immersed in the resulting evaporator. Superhydrophilicity is depended on kinds of functional group on the materials surface, especially for oxygen content functional group. Figure 3d illustrates the oxygen element for various evaporators. It is obvious that the oxygen content of samples activated by chemical agents is higher much than that of without chemical agent treatment. For instance, the oxygen content of CTP is only 3.05 wt%; after chemical activated by NaOH, the corresponding oxygen content increased to 15.05 wt%. Such high oxygen content of the resulting samples gives the 3D evaporator super hydrophilicity and can supply enough water for evaporation.

**Photo to thermal conversion properties**
For directly evaluating the light-to-thermal conversion performance of the TP based evaporators, an IR camera were employed to follow the tracks of temperature of the evaporator surface under the dry and wet condition respectively at the light intensity of 1000 W m\(^{-2}\). Under the dry and wet condition, the Na-CFTP exhibit excellent light-to-thermal performance. As shown in Fig. 5, the dry surface temperature of Na-CFTP rapidly increased from 17.5 °C to 89.6 °C only using 30 s, and further ramped up to 105.3 °C for 1 min, and then reached 130.4 °C in the next 30 min; howbeit, other samples temperature did not increase so fast and high like Na-CFTP, for instance, the final temperature of Na-CFTP is higher than those of CTP and CFTP for 13.3 °C and 9.8 °C respectively under the dry condition. Additionally, under the wet condition, the surface temperatures of Na-CFTP rapidly ramped to 44.2 °C during 3 min, and slowly grown to 53.9 °C in the next 57 minutes under one sun, which temperatures rose more speedy and higher than that of other samples as exhibited in Fig. 6. As discussed above, it is displays that Na-CFTP showed best light-to-thermal conversion performance under the dry and wet condition. Excellent light-to-thermal performance of the Na-CFTP can be attributed to its unique porous structure and high surface area that can capture the light in an efficient way and further change to heat.

**Solar steam generation performance**

Given the typical porous structure and good light capture and light-to-thermal performance of the porous Na-CFTP, we developed different height (1 cm, 5 cm, 10 cm) Na-CFTP based 3D evaporators to investigate their water steam generation performance, where the height of 1, 5 and 10 cm evaporator are named Na-CFTP\(_1\), Na-CFTP\(_5\) and Na-CFTP\(_{10}\) respectively. We firstly systematically explored the water conveying performance of the different height of the Na-CFTP evaporators. Commercial cotton rods with a length of 15 cm and a diameter of 8 cm are used as standard water absorbent, and a thermal imaging camera is used for recording the water transmission process. As shown in Fig. 7 and Figure S7, with the help of capillary effect, water can be quickly transported to the middle and top of the cotton rod for Na-CFTP\(_1\) evaporator during the 60 s and 180 s respectively. Moreover, for sample Na-CFTP\(_{10}\), water also can be transported about 2.5 cm within 3 min, and few water moisture slowly reach to the top of the cotton rod for 30 min. Obviously, With the increase of the sample height, the water transport speed in evaporator slows down. The water transmission speed is in the cotton on the Na-CFTP\(_{10}\) is slower than that of Na-CFTP\(_1\) and Na-CFTP\(_5\). The transmission speed of the water in cotton rod on Na-CFTP\(_{10}\) is slower than in other two samples, but its water transmission performance is still meet the requirements of the evaporation. Such good water transmission performance is consistent with the results of the water contact angle as shown in Fig. 4e and Figure S6.

To get the detail evaporation datum of the TP based evaporator, a home-made equipment was used to survey performance of water evaporation, where the environment humidity and temperature were kept about 40% and 25°C respectively. Here, a computer controlled electronic balance was used to keep an account of mass changes of water in container every 5 s for 1 h. As exhibited in Fig. 8a, under one sun illumination (1000 W m\(^{-2}\)), the amount of water volatilization for per hour were 1.16, 1.29, 1.49, 1.65, 1.67, 1.72, 1.89 kg m\(^{-2}\) for CTP, CFTP, Zn-CFTP, P-CFTP, K-CFTP, Cu-CFTP, Na-CFTP evaporator, respectively. As
nicely shown in Fig. 8a and b, the evaporation performance of the Na-CFTP is significantly higher than that of other chemical agents treated TP based evaporators with corresponding steady evaporation speed is 2.26 kg m\(^{-2}\) h\(^{-1}\) after one hour, which is 1.65, 1.55, 1.36, 1.11, 1.22, 1.15 times of the CTP, CFTP, Zn-CFTP, P-CFTP, K-CFTP, Cu-CFTP.

Considering the geometry of toilet paper and for better using the typical structure, different heights of TP were treated by NaOH and carbonized in an atmosphere furnace in nitrogen for 2h. As exhibited in Fig. 8c and d, With the increase of evaporation height, the evaporation rate of the TP based evaporator activated by NaOH is largely improved. Na-CFTP\(_{10}\) evaporator exhibits a much higher evaporation performance than the Na-CFTP\(_{1}\) and Na-CFTP\(_{5}\). As shown in Fig. 8c and d, when the height of the TP based evaporator increase from 1 cm to 5cm and 10 cm, the water weight loss in the cup increases from 1.89 to 2.54 and further to 3.10 kg for per m\(^{2}\), with the corresponding evaporation rate enhance from 2.26 to 2.86, and further increase to 3.37 kg m\(^{-2}\) h\(^{-1}\).

It should be noted that evaporation and apparent energy utilization rates of Na-CFTP\(_{10}\) evaporator are far beyond 1.592 kg m\(^{-2}\) h\(^{-1}\) (theoretical value) and 100%[38]. Na-CFTP\(_{10}\) has achieved such good results, on the one hand because of its rich microporous (Fig. 3c), well vertical layer-by-layer structure (Fig. 2c) and good water transportation and steam escape capacity (Fig. 4e and Fig. 7b) which can catch more lights and, own good light-to-heat conversion efficiency and provide enough water for evaporating; on the other hand because expand the water evaporation area by additional side area like the previous literature[36].

Above results demonstrated that TP based evaporator exhibits excellent solar assisted water evaporation performance. In this manuscript, we triumphantly utilize the traditional carbonized and activated technology to change the traditional, easy scale-up and cheap industrial products (Toilet paper) as high as an efficient evaporator. This would open an easy way to utilize the industrial products for solar energy utilization and distillation and desalination in future.

Outdoor Distillation and Desalination performance

To investigate the performance in practical situation of the resulting Na-CFTP\(_{10}\) evaporator, a commercialization display box (Fig. 9a) and a home-made box (Fig. 9b) were employed to collect fresh water in the outdoor. A non-stop 20-days nature solar steam generation test was carried out at Xinzhou normal university from 8:00 to 18:00. Here, the weight of the cup was record before and after experiment at every day. As exhibited in Fig. 9d, the solar steam generation performance of TP based evaporator is steady over the 20-days with an average pure water output of 21.6 kg m\(^{-2}\) day\(^{-1}\) and 20.4 kg m\(^{-2}\) day\(^{-1}\) for distilled water and simulated sea water[39–41] respectively. The prepared 3D evaporator for per square meter can meet the drinking water demand of more than 10 people. Such amazing water output ability and steady performance of the Na-CFTP is proved that TP can be as a perfect candidate to manufacture solar driven evaporator along with low-cost and easy scale-up feature. It is easy to find that
water output fluctuates with average light intensity (red dot and line in Fig. 9d) at each day. Also, the concentration of Na\(^+\), K\(^+\), Ca\(^{2+}\), and Mg\(^{2+}\) in the resulting desalinated water are reduced from the initial 11619, 376.6, 1203.2, 1052.8 mg·L\(^{-1}\) to 1.141, 0.7562, 0.6489, 0.1911 mg·L\(^{-1}\) after treated by Na-CFTP (Fig. 9c) which can meet the standards of the Environmental Protection Agency and the World Health Organization\cite{42,43}.

**Conclusion**

In summary, a 3D evaporator prepared from TP is firstly reported, which exhibits outstanding solar driven steam performance and can be act as an ideal candidate for seawater treatment because of its unique layer-by-layer porous multilevel structure system. Varied chemical agents, especially for NaOH, can effectively improve the porous structure and become more rougher of the carbon fiber surface which anchored in the carbon paper of the resulting evaporators. Obtained Na-CFTP shows as high as BET surface area of 1164.1 m\(^2\) g\(^{-1}\) and excellent evaporation rate of 3.37 kg m\(^{-2}\) h\(^{-1}\) under one sun (1000 W m\(^{-2}\)), and the average value of 20.4 kg m\(^{-2}\) day\(^{-1}\) for a 20 consecutive days outdoor experiment for treatment of stimulate sea water, respectively, which can meet the drinkable water demand for more than 10 persons. This work provides a novel way to utilizing controllable structure of commercial products for seawater treatment.

**Declarations**

**Ethical Approval** No animals were killed. There is no ethical approval needed in this work.

**Competing interests** We, the authors, hereby declare that we have no competing interests.

**Author contributions** Xidong Suo: Methodology, Conceptualization, Software, Validation, Data curation, Writing - original manuscript, Writing - review & editing, Funding acquisition, Supervision. Yao Li: Methodology, Validation, Investigation. Peiqi Liu: Investigation, Data curation. Yingying Li: Data investigation. Cuirong Guo: Investigation, Data curation. Jie Yang: Investigation, Data curation, Visualization. Hongtao Qiao: Investigation, Data curation. Sheng Han: Investigation, Data curation. Chenqi Liu: Methodology, Investigation, Data curation. Aiping yin: Investigation, Data curation.

**Funding** The authors would like to thank the funding support by: Fundamental Research Program of Shanxi Province (20210302124332), Scientific and Technological Innovation Programs of Higher Education Institutions in Shanxi (2021L448, 2021L460), Shanxi Province College Student Innovation and Entrepreneurship Training Project (2022007 2022028), Science & technology plan and project in XinZhou (20220503), Xinzhou Normal University (2020KY04). The authors also acknowledge the SEM, XPS, ICP test support from shiyanjia lab (www.shiyanjia.com).

**Availability of data and materials** The data of this manuscript are obtainable from the corresponding author Xidong Suo.
References

17. Y. Shi, O. Illic, H.A. Atwater, J.R. Greer, Nat. Commun. 12, 2797 (2021)
34. X. Min, B. Zhu, B. Li, J. Li, J. Zhu, Acc. Mater. Res. 2, 198 (2021)
42. C. Tian, J. Liu, R. Ruan, X. Tian, X. Lai, L. Xing, Y. Su, W. Huang, Y. Cao, J. Tu, Small 16, e2000573 (2020)

Figures
Figure 1

(a) Schematic illustration of preparation process for the TP based evaporators. b) Schematic illustration shows the evaporation modes in the 3D layer-by-layer consisted porous evaporator.
Figure 2

a-c) SEM images for raw TP, CTP and CFTP. d-e) Water contact angle for CTP and CFTP. f) Compression performance for CTP and CFTP.
Figure 3

(a-c) SEM images of the cross-sections of CTP, CFTP and Na-CFTP respectively.
Figure 4

(a). $N_2$ adsorption–desorption curves of CTP, CFTP and Na-CFTP. (b) Pore-size distribution curves of CTP, CFTP and Na-CFTP. (c) UV–vis-NIR absorption curve of CTP, CFTP and Na-CFTP. (d) Carbon, nitrogen and oxygen weight content of CTP, CFTP and Na-CFTP. (e) Water contact angle for Na-CFTP.
Surface temperature of the TP based evaporator recorded by IR camera under dry condition at one sun.

Figure 5

<table>
<thead>
<tr>
<th>Irradiation time (min)</th>
<th>Under the dry condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Irradiation time (min)</th>
<th>Under the wet condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>
Figure 6

Surface temperature of the TP based evaporator recorded by IR camera under wet condition at one sun.

Figure 7

Water transporting performance of different height Na-CFTP based evaporator.
Figure 8

(a) The dependence of water mass change with the irradiation of time for various TP based evaporator under one sun; (d) The dependence of evaporation rate with the irradiation of time for various TP based evaporator under one sun; (c) The dependence of water mass change with the irradiation of time for different heights of Na-CFTP based evaporator under one sun; (d) The dependence of evaporation rate with the irradiation of time for different heights of Na-CFTP based evaporator under one sun.
Figure 9

(a) and (b) Photos of outdoor experiment installation acting as a solar water evaporation system during daytime; (c) The concentrations of Na\(^+\), K\(^+\), Ca\(^{2+}\), and Mg\(^{2+}\) ions before and after desalination for Na-CFTP\(_{10}\) evaporator. (d) The amount of collected water for the sample of Na-CFTP\(_{10}\) evaporator under natural sunlight in the Xinzhou normal university (Xinzhou City, Shanxi Province, China) for pure water and simulated seawater.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- GraphicalAbstract.png
- SupplementaryMaterial.docx