Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.

Supplementary information

Jute Stick Derived Self-regenerating Sustainable Solar Evaporators with Different Salt Mitigation Mechanisms for Highly Efficient Solar Desalination

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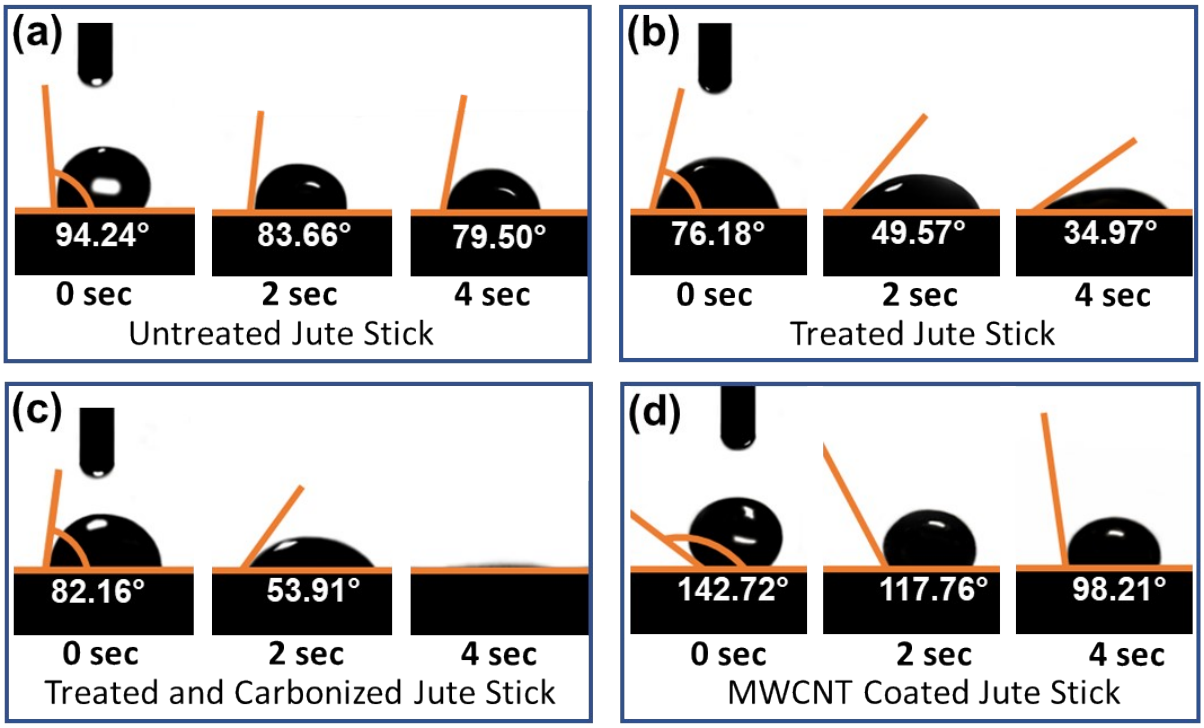

Fig. S1: Wettability of the surfaces. a) Untreated JS. b) Treated JS (PJS). c) Treated and Carbonized JS (CJS) d) MWCNT coated JS (MJS)

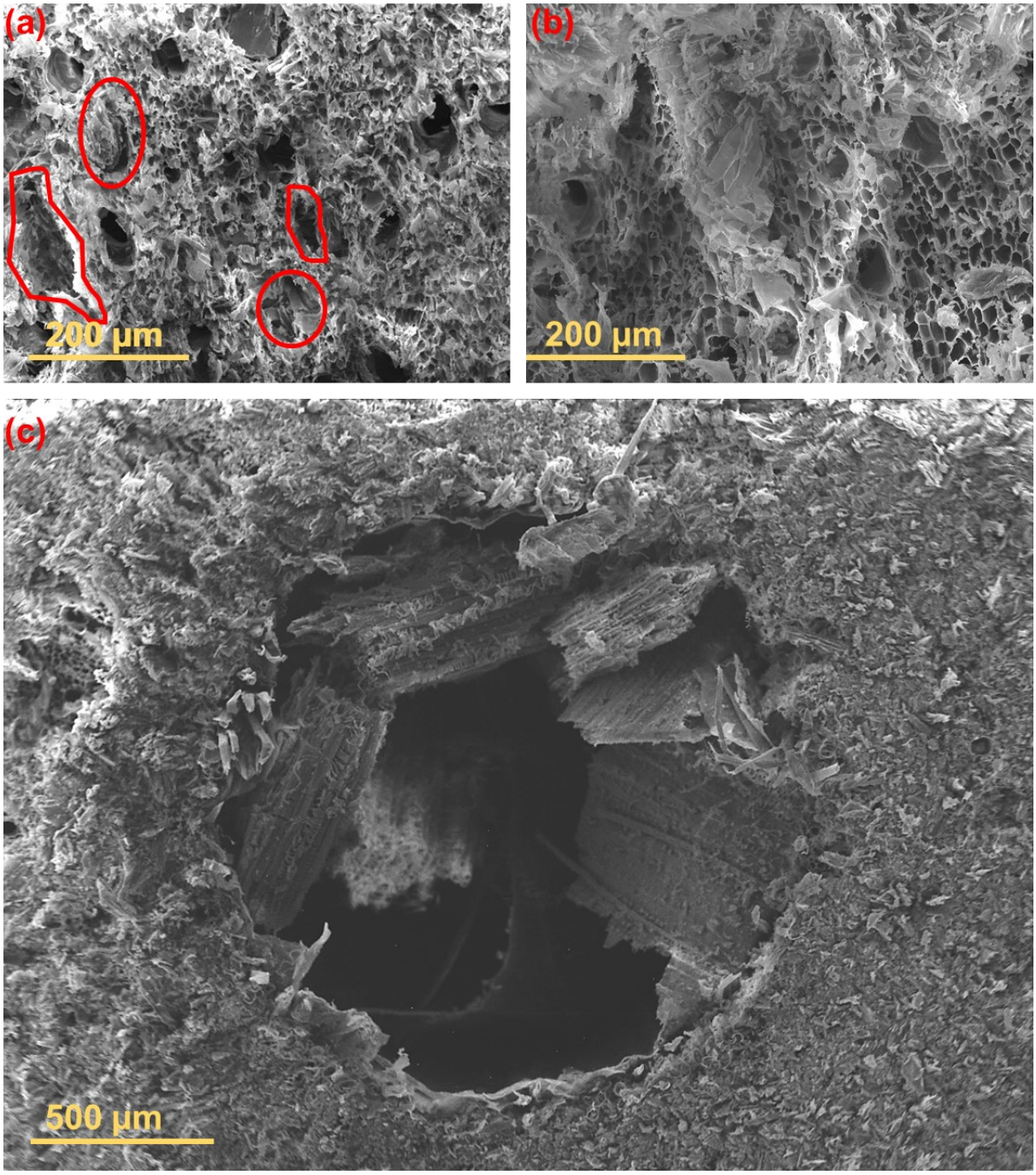

Fig. S2: Surface morphology of JS. SEM image of a) Carbonized JS surface (Hot plate carbonization) showing the micro-cracks caused by uneven heating. b) Carbonized JS surface (carbonization by even heating in the presence of Argon (Ar)). c) Untreated and uncleaned JS with central natural hole of ≈1.6 mm diameter.

Supplementary Note 1:

Effect on surface morphology due to carbonization by even and uneven heating:

In this article hot plate carbonization technique was adopted to carbonize the alkali treated JS for fabricating the solar absorbing surface. The alkali treated JS pieces were kept on the top of preheated (400 ºC) hotplate for 14 minutes. As the JS has low thermal conductivity, the temperature of one surface (in contact with hot plate) became very high than another surface which causes micro-cracks on the solar absorbing surface of carbonised JS evaporators as shown in Fig. S2a. For further verification some JS pieces were carbonised inside a tube furnace in the presence of Argon (Ar). The temperature of the tube was increased very slowly (15 ºC/min to reach 400 ºC) for even heating of JS and kept at that temperature for 10 minutes and after that it was cooled to room temperature very slowly in the presence of Ar. Fig. S2b shows the surface morphology of carbonized JS (evenly heated) where such microcracks were not observed. However due to long exposure to heat and total carbonization of JS, these samples became soft and difficult to handle during solar evaporation experiment and hence these samples were only used for morphology comparison.

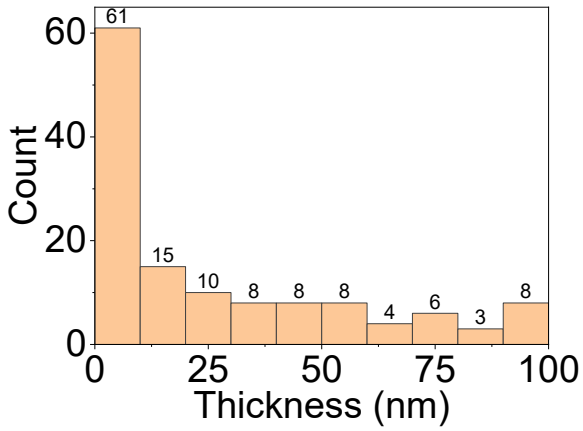

Fig. S3: Statistical distribution of the thickness of 131 particles found after 8 hours of ultrasonication of MWCNT in IPA

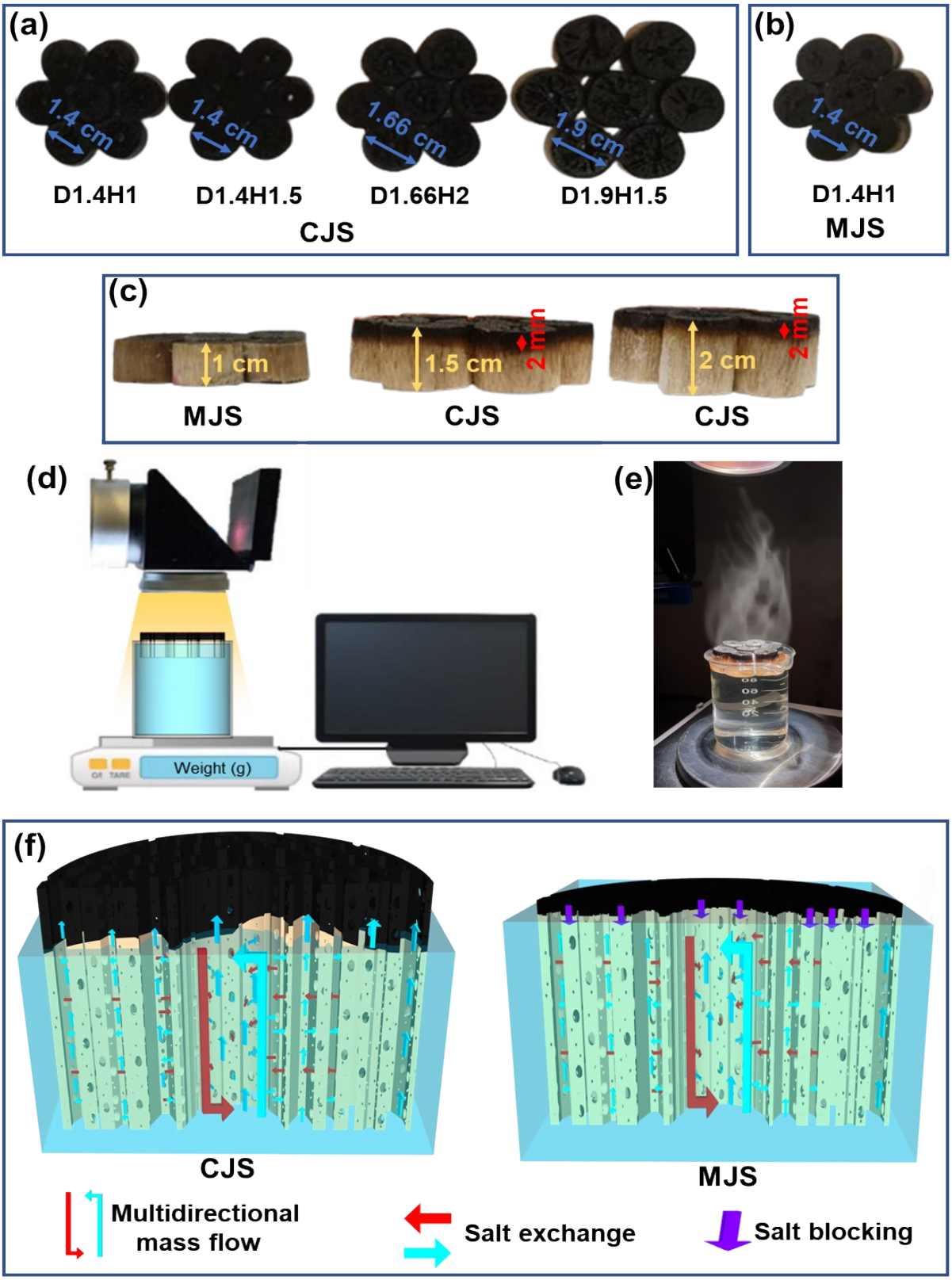

Fig. S4: Dimensions of the evaporators. a) Dimensions of CJS. b) Dimension of MJS. c) Image of 3 different thicknesses of the evaporators d) Schematic illustration of experimental set up e) illustration of steam generation. f) Salt mitigation mechanism of CJS and MJS.

Supplementary note 2

Dimensions of the evaporators:

Jute Stick (JS) has been cut horizontally to the growth direction at different vertical position of JS to get evaporators of different diameters and thicknesses. Initially 4 carbonized CJS arrays of 3 different diameters and 3 different thicknesses were made. 7 JS pieces with diameter of 1.4 cm and thickness of 1 cm are carbonized together and grouped in a hexagonal arrangement to make CJS_D1.4H1. It should be noted that the diameter and thickness of each JS pieces is 1.4 cm and 1 cm respectively and hence while naming the CJS evaporators, diameter and thickness of each piece are considered. Similarly, 7 JS pieces with diameter of 1.4 cm and thickness of 1.5 cm are carbonized and grouped together to make CJS_D1.4H1.5. Same procedure was followed for making CJS_D1.66H2 and CJS_D1.9H1.5. The average diameters of the central natural hole of each jute stick were 2.5 mm for CJS_D1.4H1 and CJS_D1.4H1.5 and 4 mm for CJS_D1.66H2 and CJS_D1.9H1.5 after cleaning and drying and carbonizing. For preparing MJS 7 JS pieces with diameter of 1.4 cm and thickness of 1 cm was used. The diameter of the natural hole of each JS pieces of MJS was 2.5 mm after cleaning and drying.

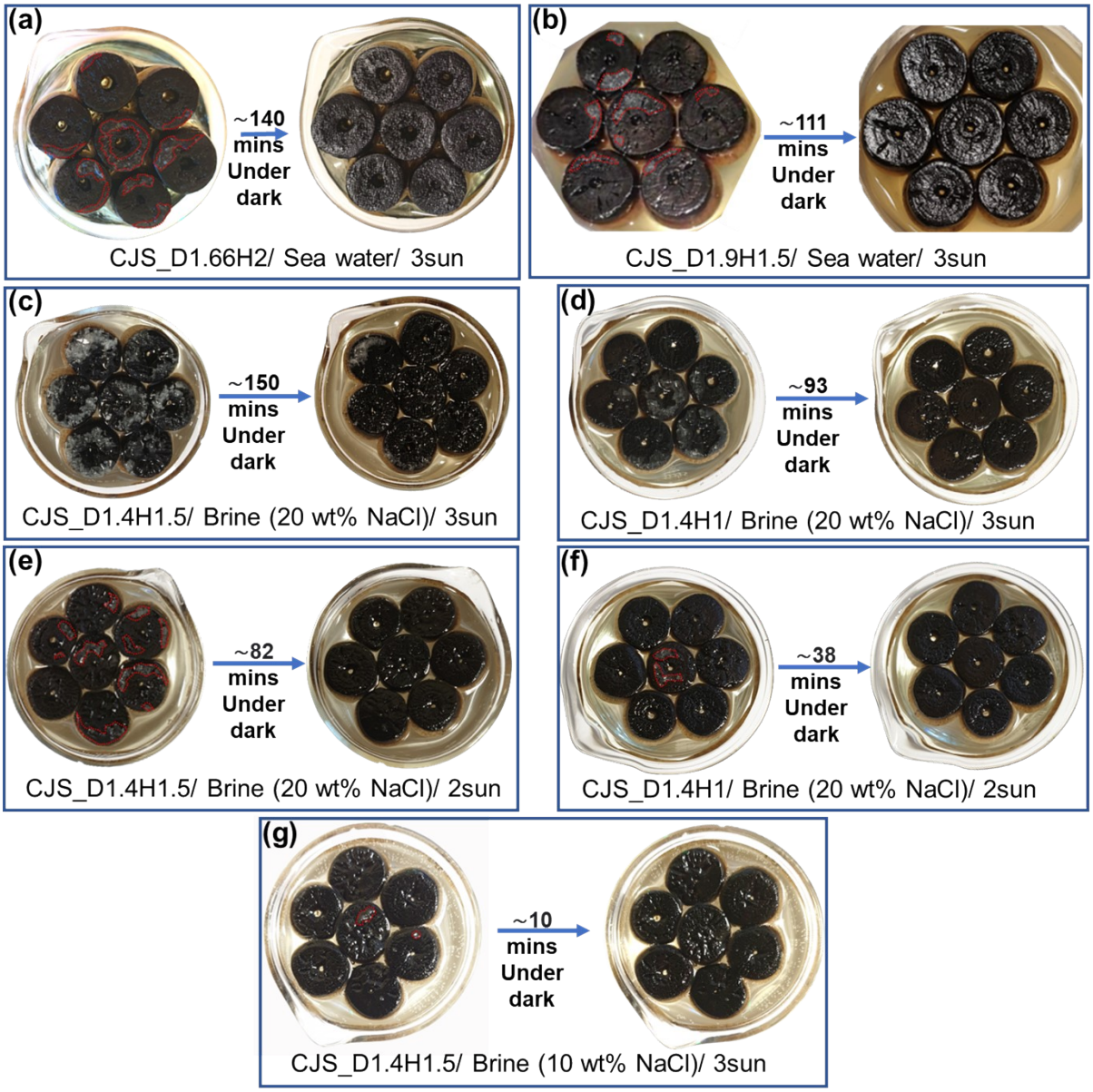

Fig. S5: Accumulated salt rejection time for different CJS evaporators. a) Accumulated salt on the top surface of CJS_D1.66H2 after 1 hour of seawater evaporation under 3 sun and rejection of the accumulated salt under dark condition. b) Accumulated salt on the top surface of CJS_D1.9H1.5 after 1 hour of seawater evaporation under 3 sun and rejection of the accumulated salt under dark condition. c-d) Accumulated salt on the top surface of CJS_D1.4H1.5 and CJS_D1.4H1 after 1 hour of brine water (20 wt% NaCl) evaporation under 3 sun and rejection of the accumulated salt under dark condition. e-f) accumulated salt on the top surface of CJS_D1.4H1.5 and CJS_D1.4H1 after 1 hour of brine water (20 wt% NaCl) evaporation under 2 sun and rejection of the accumulated salt under dark condition. g) accumulated salt on the top surface of CJS_D1.4H1.5 after 1 hour of brine water (10 wt% NaCl) evaporation under 3 sun and rejection of the accumulated salt under dark condition.

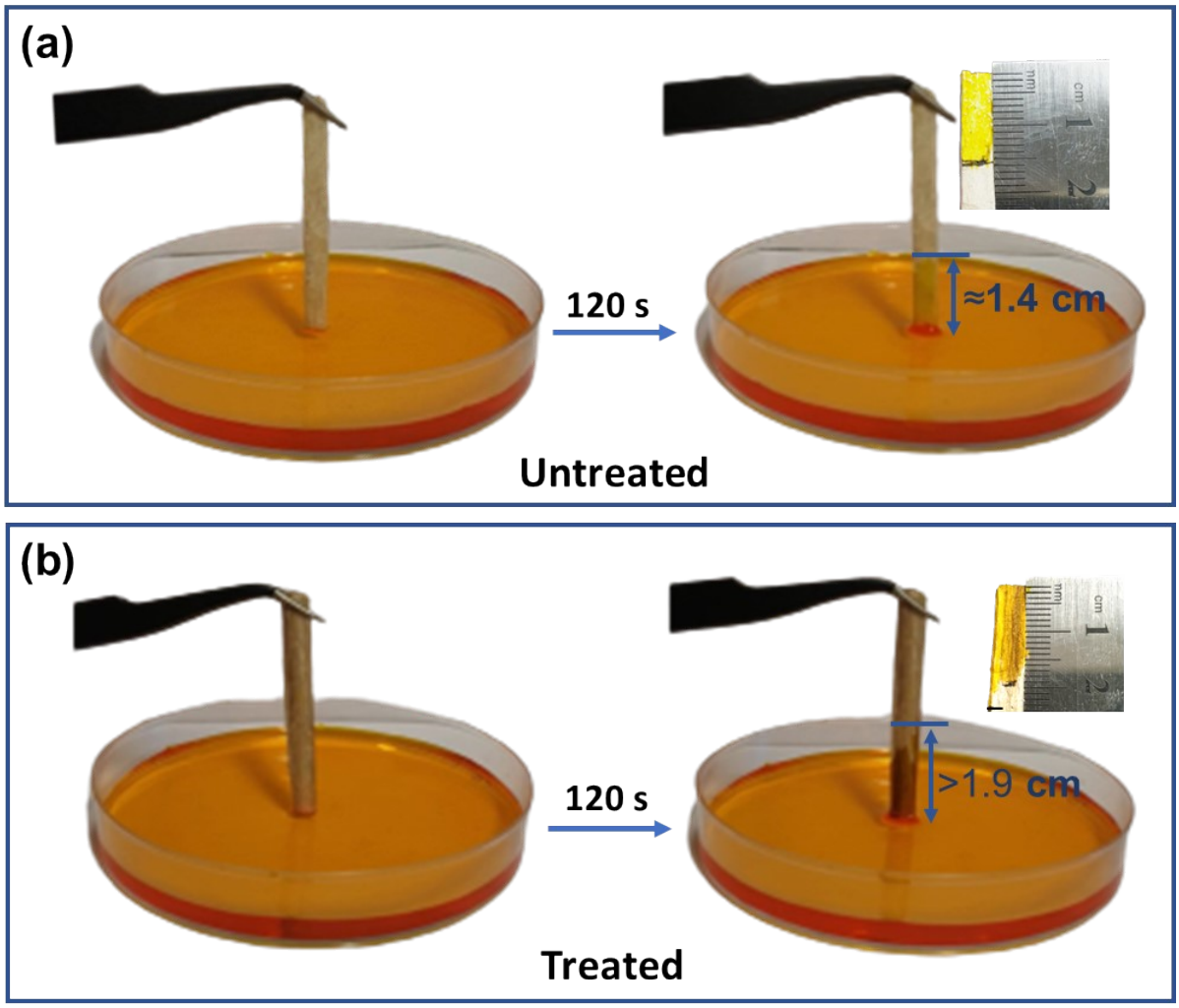

Fig. S6: Water Uptake experiment a) Untreated JS b) NaOH Treated JS

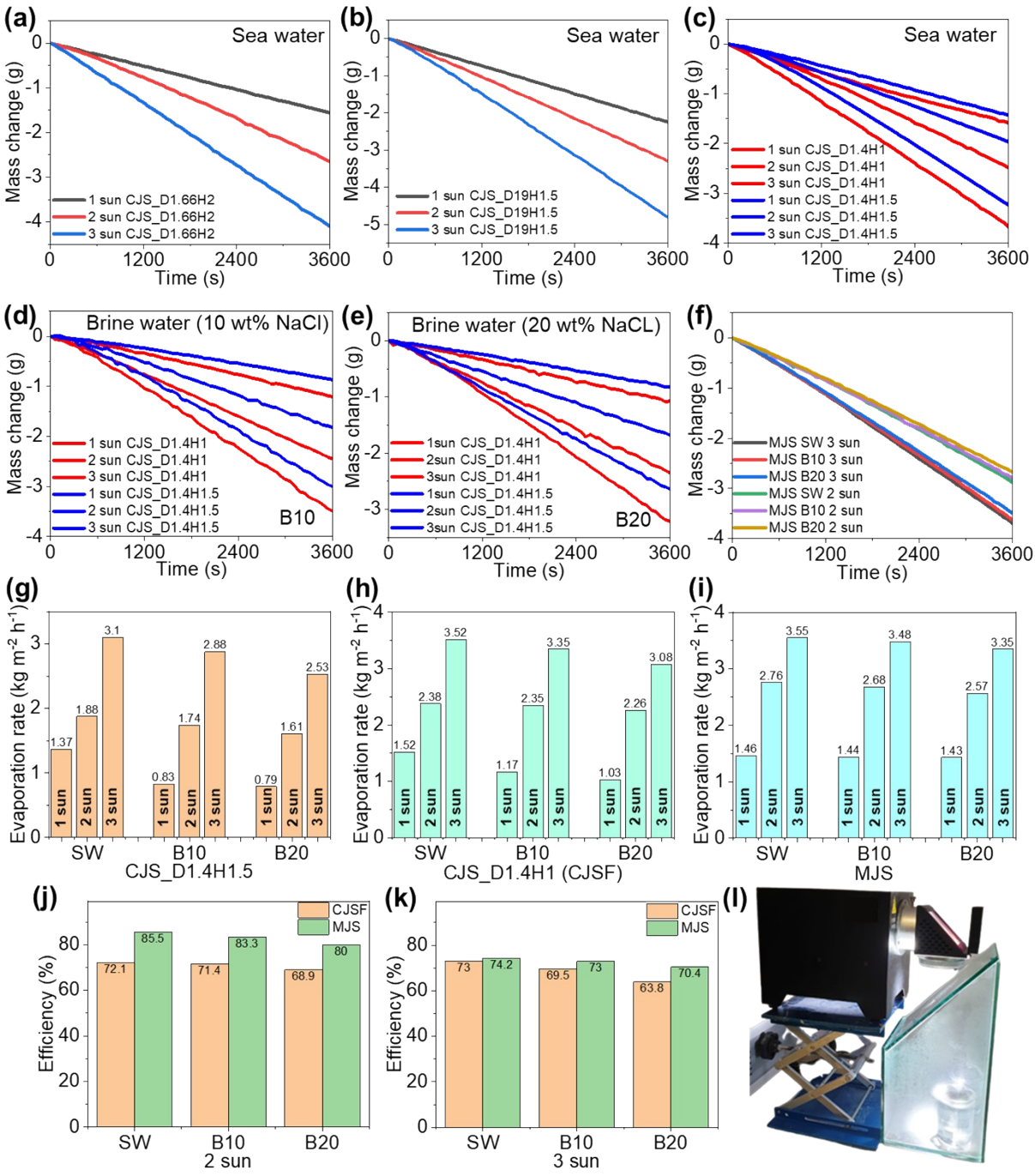

Fig. S7: Mass change rate evaporation rate and efficiency of different solar evaporators. a) Mass change rate of sea water (SW) in the presence of CJS_D1.66H2 under different solar illumination. b) Mass change rate of sea water (SW) in the presence of CJS_D1.9H1.5 under different solar illumination. c) Mass change rate of sea water (SW) in the presence of CJS_D1.4H1 and CJS_D1.4H1.5 under different solar illumination. d) Mass change rate of 10 wt% NaCl Concentrated Brine water (B10) in the presence of CJS_D1.4H1 and CJS_D1.4H1.5 under different solar illumination. e) Mass change rate of 20 wt% NaCl Concentrated Brine water (B20) in the presence of CJS_D1.4H1 and CJS_D1.4H1.5 under different solar illumination. f) Mass change rate of SW, B10, B20 in the presence of MJS under different solar irradiation (2 sun and 3 sun). g-i) Evaporation rate of SW, B10 and B20 in the presence of CJS_D1.4H1.5, CJS_D1.4H1 (CJSF) and MJS under different solar irradiation. j-k)

Efficiency of CJSF and MJS in evaporating SW, B10 and B20 under different solar irradiation (2 sun and 3 sun). I) Image of generation and condensation of vapor.

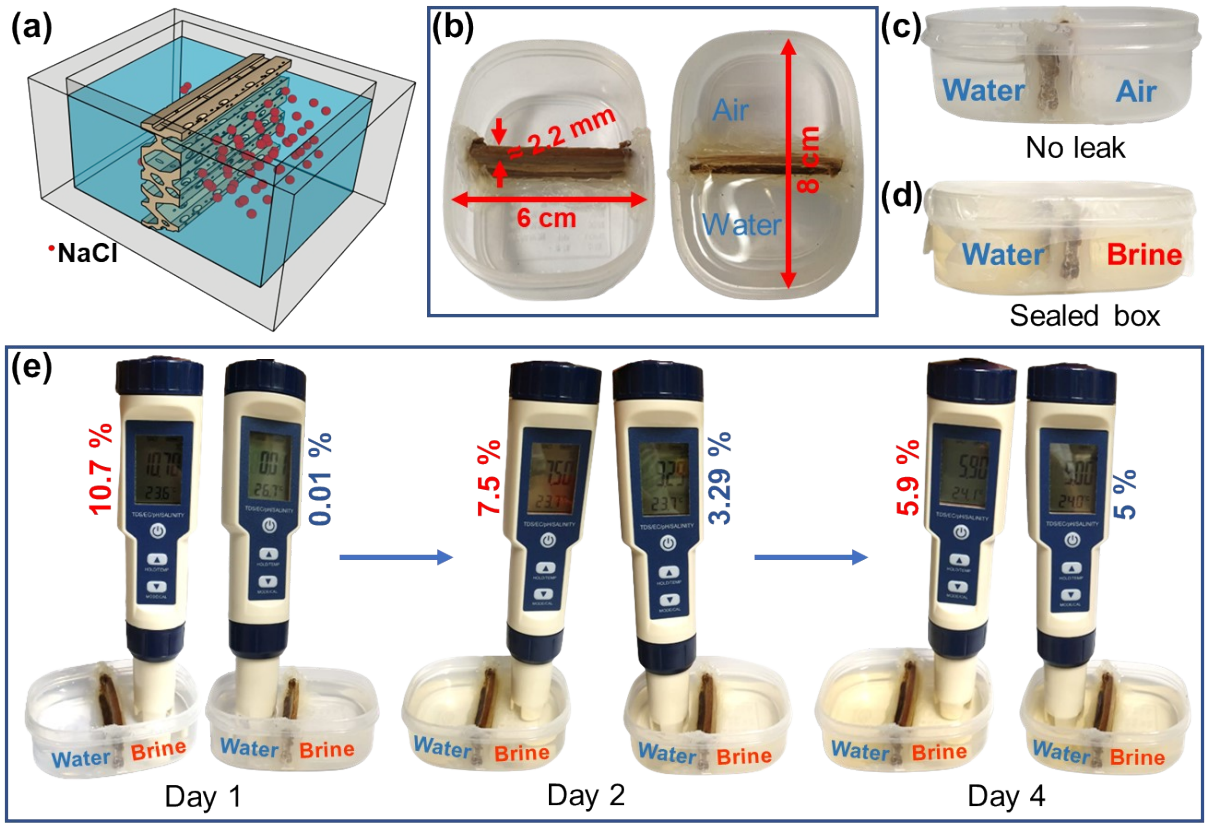

Fig. S8: Experiment on lateral salt transfer through pits. a) schematic illustration of lateral salt transfer through pit. b) System used for experimentation. c) checking water leakage from the sides of JS segment. d) Sealed box containing tap water (salinity 0.01%) on one side and brine water (salinity 10.7%) on another side. e) salinity measurement.

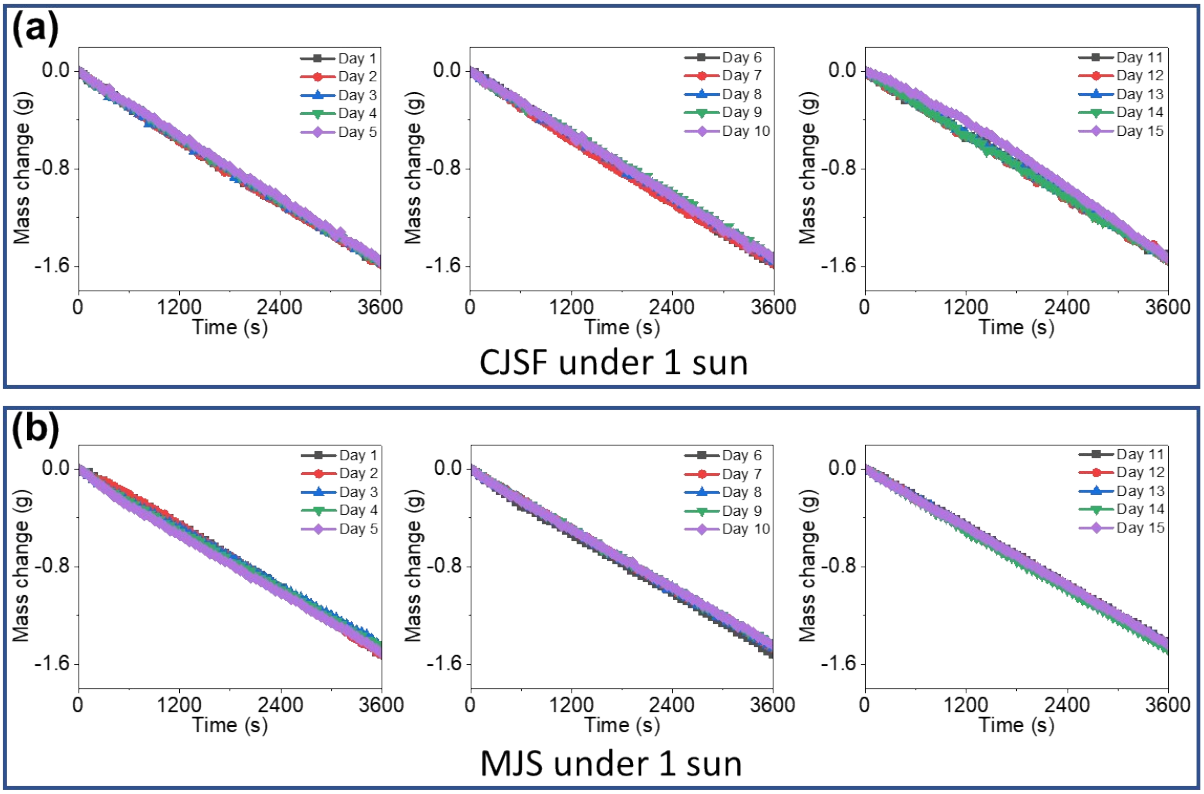

Fig. S9: Mass change data for 15 consecutive days (runtime of 1 hour) of operation for a) CJSF and b) MJS.

Supplementary note 3

Evaporation rate and Efficiency calculation:

The evaporation rate, m_e can be calculated by following equation:

$$m_{ev} = \frac{m_h}{A} \quad (1)$$

Where, m_h is mass loss of water per hour due to evaporation and A is the area of evaporation surface.

The efficiency can be calculated by

$$\eta_s = \frac{m_l\,(H_{lv} + Q)}{E_i} \quad (2)$$

$$H_{lv} = 1.91846 * 10^6 * [T_a/(T_a - 33.91)]^2 \quad (3)$$

$$Q = c * (T_a - T_i) \quad (4)$$

Where, m_l = net evaporation rate (kg m^{-2}),

$$m_l = m_{ev} - m_{dr} \quad (5)$$

In these equations

m_{dr} = dark evaporation rate

E_i = energy input of the incident light (kJ $m^{-2}h^{-1}$),

H_{lv} = is the latent heat required for vaporization of water (J kg^{-1}),

T_a = is the average temperature of the solar evaporation surface (K),

Q = is the required heat for increasing the temperature of water,

c = is the specific heat of water (4.2 J g^{-1} K^{-1}),

T_i = initial average temperature of top surface (K)

For CJSF evaporator under 1 sun illumination, T_a ≈ 309.5 K, T_i ≈ 296.6 K, m_{ev} ≈ 1.52 kg m^{-2} h^{-1}, m_{dr} ≈ 0.24 kg m^{-2} h^{-1}, Hence, from the above-mentioned equations the efficiency becomes ≈ 86.19% for water. For sea water efficiency is ≈ 87.01% as m_{dr} ≈ 0.22 kg m^{-2} h^{-1}.

For MJS evaporator under 1 sun illumination, T_a ≈ 307.8 K, T_i ≈ 296.6 K, m_{ev} ≈ 1.46 kg m^{-2} h^{-1}, m_{dr} ≈ 0.24 kg m^{-2} h^{-1}, Hence, from the above-mentioned equations the efficiency becomes ≈ 81.94% for water. For sea water efficiency is ≈ 84.39% as m_{dr} ≈ 0.20 kg m^{-2} h^{-1}.

Supplementary note 4:

Standard deviation in evaporation rate

The standard deviation of the evaporation rate of tap water and sea water were calculated using the following equation:

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}} \quad (6)$$

Here,

σ = The population standard deviation

x_i= Each value from the total population

μ = Mean of the population

N =Size of the population

Supplementary note 5

Mass water absorption

$$a_{mw}\,(\%) = \frac{m_{wet} - m_{dry}}{m_{dry}} X\ 100 \qquad (7)$$

Here,

m_{wet}= mass of wet evaporator (CJSF) after submerged in water for 20 minutes = 6.122g

m_{dry} = mass of the dry evaporator (CJSF) = 2.038g

Hence from above equation mass water absorption after 20 minutes = 200.39%

Fig. S10: Mass of dry and wet evaporator.

Table ST: The efficiency, evaporation rate and comments on different biomass based Solar Evaporator.

Evaporator	Evaporation rate (kg m^{-2} h^{-1})	Efficiency (%)	Type of water	Ref.
Carbonized Mushroom	1.475	78	Water under 1 sun	[1]
Carbonised basswood blocks (Mechanically modified by drilling)	1.04	≈ 75	20 wt% NaCl Concentrated brine water under 1 sun	[2]
Bamboo charcoal	1.191	84	Salt water (3.5 wt%) under 1 sun	[3]
Janus Pomelo Peel with MXene	≈1.48	≈92.3	Water and 3.5 wt% NaCl concentrated water Under 1 sun illumination	[4]
Chinese ink coated mechanically modified (by drilling)	≈ 1.6	74	3.5% NaCl concentrated water under 1 sun	[5]
Reduced graphene oxide/ silver/wood	3.920	92.91	Sea water under 3 suns	[6]
Carbonized daikon	1.57	85.9	Water under 1 sun	[7]
Carbonized 3D Platanus Fruit	2	81.3	Water under 1 sun	[8]
Fe3O4/polyvinyl alcohol decorated delignified wood	≈1.3	≈73	3.5 - 20 wt% NaCl Concentrated water under 1 sun	[9]
Carbonized Food Waste (rice, potato, banana peel, Pasta, Lotus root)	≈1.34 for Pasta (best performance)	≈ 84.1	water of 3.5 wt% salinity under 1 sun	[10]
All biomass-based squid ink-starch hydrogel	≈ 1.94	-	3.5 wt% salt water under 1 sun	[11]
Surface-carbonized bimodal porous	≈ 0.8	57	15 wt% NaCl concentrated water under 1 sun	[12]

wood membrane				
Polypyrrole-wood	1.32	≈ 83	Simulated sea water of 3.5 wt% salinity under 1 sun	[13]
CJS	1.52	87.01%	Natural seawater (salinity of 2.98% with other impurities) under 1 sun	This work
MJS	1.46	84.39%	Natural Seawater under 1 sun	
MJS	1.44	84.13%	10 wt% NaCl concentrated brine water under 1 sun.	
MJS	1.43	84.07%	20 wt% NaCl concentrated brine water under 1 sun.	

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