

Micro-porous aluminum nitride wick for non-photo-thermal desalination

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Abstract. Aluminum nitride is a white, hydrophilic, high-band-gap ceramic. Here we report on the light-induced evaporation of saltwater through a capillary wick composed of drop-cast microparticles. Saltwater evaporation rates are significantly higher than expected. Our results point to significant potential for this interface-driven approach in solar non-thermal desalination and water separation technologies.

1 Introduction

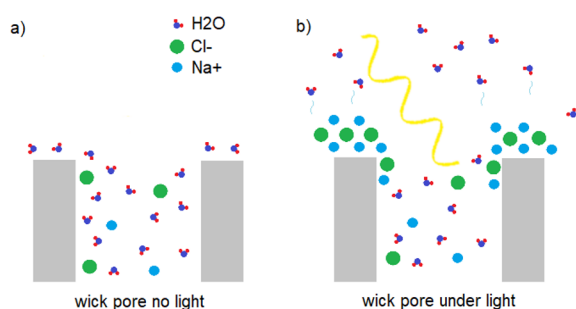


Figure 1. Schematics of interfacial nucleation with light. a) Aluminum nitride pore, where water rises to the surface of the wick via capillary action and forms both a meniscus at the pore exposed to the environment as well as a film of water at the exposed surfaces. b) Light illumination leads to water evaporation at the liquid-vapor interface, where salt crystallizes onto the aluminum nitride wick at the edges of the pores.

Solar desalination processes are generally centered on achieving maximal light absorption and conversion to heat, which evaporates and separates water from a salt-water reservoir. There are a few unavoidable challenges to contend with in the thermal desalination paradigm. Firstly, the water-to-steam conversion is an energy-intensive process due to the high latent heat of vaporization of water. Inefficiency arises from any leakage of heat (conduction, convection, thermal radiation) to the bulk reservoir [1]. These issues also affect strategies for zero liquid discharge, where the remaining waste brine in the reservoir maintains the same salinity. In order to achieve zero-liquid discharge, salt is removed via nucleation during the evaporation process. This minimizes the impact that desalination waste has on the environment [2].

The salt nucleation may prohibitively reduce the efficiency of desalination processes, however. Over 100% efficiencies have been achieved with multistage processes

that reduce leakage with infrared-reflecting windows and surfaces that recapture the heat released from the vapor condensation [3]. The major weakness with these methods is associated with the “salting out” that occurs, which is when salt crystallizes inside the pores of the wick material, impedes water flow, blocks light and therefore heat generation. Localized evaporation and salt crystallization can be a boon to control salt nucleation and fix the critical salinity of the reservoir. Evaporation ideally occurs at the wick surface to avoid salting out [4] [Fig. 1].

Here, we demonstrate on a non-photo-thermal approach to achieve higher evaporation with a wide bandgap ceramic, which may enable new solar desalination and zero-liquid discharge technologies. Our approach to break the strong ion-dipole bonds of salt in water is to exploit the high-bandgap of a ceramic such as aluminum nitride. The Al-N bandgap energies are 6.2, 6.9, and 7.2 eV, which yields a density of states which aligns with the salt-water binding energy [5, 6]. It is the NaCl in the solution that selectively absorbs 193 nm and 215 nm wavelength UV light [7].

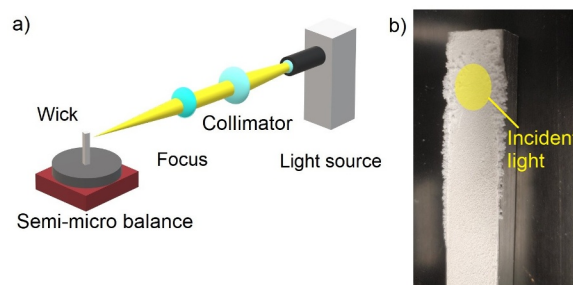


Figure 2. a) General setup of the experiment. b) Pictures of the wick showing salt on the edges of the wick after a trial. The yellow circle indicates where the light is focused

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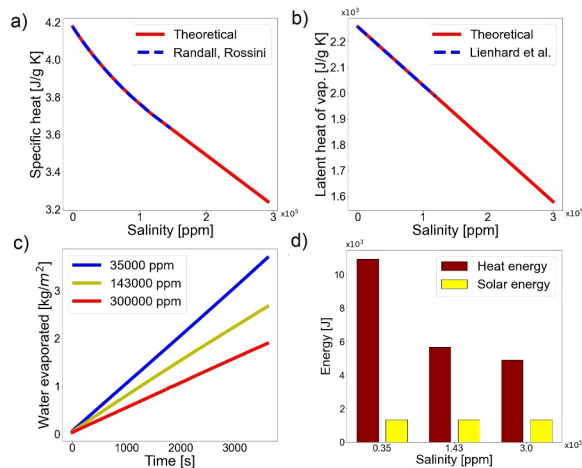


Figure 3. Extrapolation of a) specific heat and b) latent heat of vaporization. c) Mass change as a function of time for 3 salinities. d) Comparison of the effective thermal energy and the actual energy from light needed for evaporation.

2 Experiment

We fabricate a porous wick with 10-micron aluminum nitride particles. Capillary action moves 'packets' of salt water to the light source. The packing of the particles should not be close; it is important that they form capillaries, but not so small that they impede the movement of the water molecules [8]. We study the evaporation that influences the movement of water in the pores.

Figure 2 shows the experimental setup. Light from a solar simulator is collimated to a 1-cm-diameter area with 350-mW power (approximately 3 suns). The wick is placed in a reservoir and illuminated with light for 800 minutes. The mass change is monitored. The experiments are performed with 35000, 143000, and 300000 ppm salt water solutions to simulate sea water, high-salinity brine, and runoff brine. Mass measurements are taken on micro-balance every minute. We study the effect of light illumination intensity and illumination areas, salinity, and wick properties, and illumination. We also study monitor effects associated with salt damage to the wick over 12 trials with each wick.

3 Results

The solutions with lower salt concentration achieve higher evaporation rates, as expected. Higher salt concentrations raise the vapor pressure of the solution; as the salt concentration increases, it is harder for the water molecules to evaporate, which can be associated with boiling point elevation [9, 10]. At the same time, the specific heat and heat of vaporization decrease with higher salinities. In order to evaluate our results, we use relations from [11] and [12], and extrapolate their curves to match our data,

shown in Figs. 3(a-b). With the effective illumination of 3 suns, the drop-cast solar wick reaches evaporation rates of 3.7 kg/m²/h, 2.7 kg/m²/h, and 1.9 kg/m²/h with 35000

ppm, 143000 ppm, and 300000 ppm salt solution, respectively. These rates represent the slopes of the mass per time curves in Fig. 3(c). Significantly more water is evaporated than expected given the illuminated light power of 3 suns. For our system, the energy comparison between thermal boil and our solar desalination wick system ranges 3-8X [Fig. 3(d)].

4 Conclusion

We demonstrate an approach that exploits the wide bandgap energy of a porous ceramic wick to facilitate the interfacial nucleation of salt from water. Since salt-water selectively absorbs photons at this bandgap energy, our method offers a route to non-photo-thermal desalination and water separation processes.

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References

- [1] O. Vincent, A. Szenicer, A.D. Stroock, *Soft Matter* **12**, 6656 (2016)
- [2] Z. Xu, L. Zhang, L. Zhao, B. Li, B. Bhatia, C. Wang, K.L. Wilke, Y. Song, O. Labban, J.H. Lienhard et al., *Energy & Environmental Science* **13**, 830 (2020)
- [3] Z. Wang, T. Horsman, A.P. Straub, N.Y. Yip, D. Li, M. Elimelech, S. Lin, *Science Advances* **5**, eaax0763 (2019)
- [4] H. Liu, Z. Huang, K. Liu, X. Hu, J. Zhou, *Advanced Energy Materials* **9**, 1900310 (2019)
- [5] S. Yamabe, H. Kouno, K. Matsumura, *The Journal of Physical Chemistry B* **104**, 10242 (2000)
- [6] J. Li, K.B. Nam, M.L. Nakarmi, J.Y. Lin, H.X. Jiang, P. Carrier, S.H. Wei, *Applied Physics Letters* **83**, 5163 (2003)
- [7] G.T. Dair, *Archives of Ophthalmology* **119**, 533 (2001)
- [8] J. Fan, H. Wu, F. Wang, *Physics of Fluids* **32**, 012001 (2020)
- [9] M. Bialik, P. Sedin, H. Theliander, *Industrial & Engineering Chemistry Research* **47**, 1283 (2008)
- [10] D. Meranda, W.F. Furter, *Journal of Chemical & Engineering Data* **22**, 315 (1977)
- [11] M. Randall, F.D. Rossini, *Journal of the American Chemical Society* **51**, 323 (1929)
- [12] M.H. Sharqawy, J.H. Lienhard, S.M. Zubair, **16**, 354 (2010)