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Numerical Analysis of the Photo-thermal Effect on Carbon-Based Films for Solar-Driven Water Desalination

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Extended Abstract

Due to a changing climate caused by the greenhouse effect, environmental contamination and an ever-growing population, many people are currently suffering from severe freshwater shortages. Traditional desalination processes such as reverse osmosis (RO) and multi-stage flash distillation (MSF) have been thoroughly developed to fulfil the global freshwater demand [1]. However, these energy-intensive processes typically consume 5 to 26 times as much energy as the theoretical minimum for water evaporation (~2400 kJ/kg) [2]. A common eco-friendly approach is the utilization of inexhaustible solar energy in solar-powered water desalination systems, wherein brackish water is evaporated under natural sun light. Solar-thermal energy conversion efficiencies in these systems have been limited to 30-40% (for a single basin solar still) [3] as a result of large thermal losses to the bulk-water reservoir and the surrounding environment.

Recently, a wide range of nanomaterials with high absorption over the broad solar spectral region, mostly metallic nanoparticles (especially those with localized surface plasmon resonance properties) [4], nanocrystals [5] and nanoshells [6], [7] have been dispersed in water and investigated for their ability to generate concentrated thermal energy to improve the efficiency of solar-driven water desalination. Furthermore, in addition to particulate absorbers, structures including carbon-based films [8], foams [9] and aerogels [10] floating at the air-water interface have also been designed and exhibit great potential to advance photo-thermal conversion in solar desalination systems.

In this work, the performance of a porous carbon-based film as a black absorber that enhances localized heating under solar radiation to power the desalination process is studied. Initial numerical results from our heat transfer analysis indicate that thermal losses to the bulk water caused by natural convection dominate over all other heat loss mechanisms, and thus lead to low conversion efficiencies. By inserting a layer with low thermal conductivity - cellular glass and polystyrene foam for example - between the carbon-based film and the bulk water, the dominant convective losses from the hot film can be reduced significantly (about two orders of magnitude) due to the confinement of thermal energy by the insulation layer, reserving more heat to accelerate water evaporation.

We've also studied the benefits of using solar concentrators to drive the water evaporation process on carbon-based films situated at the air-water interface. That is, the dependence of the desalination efficiency and thermal losses to the surrounding environment on the intensity of the incident solar irradiance (e.g. the solar concentration factor) is determined. Furthermore, we investigate carbon-based films that are configured as ordered arrays at the air-water interface. In this configuration only a portion of the surface area at the air-water interface is occupied by the carbon-based film, and the solar irradiance is concentrated onto these regions. Time-dependent simulations in COMSOL will be applied to the aforementioned array configurations to optimize the dimensions of the arrays for the purpose of maximizing the water desalination rate. The analysis carried out in this work will provide 1) better insights of localized solar heating using carbon-based films as black absorbers for the solar-driven water desalination process and 2) recommendations for the design of improved solar desalination systems.

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