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Development of solar absorbing nanoporous membranes for direct solar seawater desalination

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ABSTRACT

Because of the abundance of solar energy, solar-based desalination is an attractive technology to meet the ever-increasing water demand. In this study, we develop efficient, low cost, and optimized nanoporous membranes for direct solar desalination of seawater. Our objective is to develop a black-body like membrane that maximizes solar absorption via the structure design and coating. To fabricate our envisioned solar absorbing membranes, we developed two different and distinct approaches, the first being a flat-sheet membrane via phase inversion and the second via chemical vapor deposition. The absorbance for each membrane was measured using a UV(vis) spectrometer. The structures of the prepared membranes were characterized and observed by scanning electron microscopy and atomic force microscopy. The meanflow pore size, bubble point pore size and pore size distribution were measured using a capillary flow porometer. Also, the porosity was calculated experimentally using a gravimetric method using Salwick as a wetting liquid. Contact angle measurements were also performed to know the hydrophobic/hydrophilic nature of the membranes. In CNT, the absorption and the porosity increase as the PVDF concentration decreases while the contact angle increases as the PVDF concentration increases. The contact angle measurements for the AC and graphene membranes with different rates decrease with the increase of the activated carbon and graphene percentage in the membrane. The graphene has the highest absorption form all the membranes approximately 97%.

Keywords: Membrane distillation; Polyvinylidene fluoride; Hydrophobic; Coating

1. Introduction

In nature solar energy is the primary driving force for the formation of fresh water from oceans and seas. The energy demands and combined the need for freshwater is particularly challenging, due to the arid, humid, dry, hot and a desert environment with frequent dust storms in the Arabian Gulf region. Because of the abundance of solar energy, solar-based desalination is an attractive technology to meet the ever-increasing water demand.

The main purpose of this research proposal is looking up in developing the water desalination system, which at the end can be combined into the spectral splitting configuration. Other water desalination can be from these advancements too. In water desalination system proposal, the solar energy is absorbed into a nanoporous membrane with a spectrally eclectic surface. By this method, thermal energy can be possessed maximally with less radiative losses. The water will evaporate from top of the nanopores after the heat is delivered to the membrane. Using a condenser, the generated vapor is condensed to produce a clean water as shown in the below figure. The membrane design and development is the key novelty of the work. Specifically, the membrane has to have high rate of desalination (evaporation), spectral selectivity in order to maximize the solar radiation absorption, anti-fouling in order to lessen significant clogging and decreases efficiency over time.

Membranes can be fabricated using many types of materials, polyvinylidene fluoride (PVDF) is an attractive MD membrane material, which can be made into membranes via phase inversion. It has low surface energy, good thermal stability and low conductivity. Also, activated carbon was used as active materials for its high capacitance performance and the low-cost attribute. Carbon nanotube (CNT) which is large molecules of pure carbon that are long, thin, and it has a shape such as tubes with diameter in nanoscale.

2. Statement of the problem

Water scarcity is a major global challenge. While many large-scale technologies are being developed for clean water such as reverse osmosis and multi-stage flash, high energy

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demand can make it impractical, especially for point-of-use systems and remote infrastructure. Solar-based desalination is an attractive alternative with the abundance of solar energy.

In this study, we develop efficient, low cost and optimized nanoporous membranes for direct solar desalination of seawater. However, in order to do that, we will fabricate and experimentally characterize various polymeric membranes towards a low-cost approach. We will also explore various solar absorber coatings that can effectively maximize the heating of the membrane with minimal losses.

3. Objectives

In this study, we develop efficient, low cost and optimized nanoporous membranes for direct solar desalination of seawater. Our objective is to develop a black-body like membrane that maximizes solar absorption via the structure design and coating. The structural design involves hierarchal structures with increased roughness and hence forth increased surface area available for solar energy absorption. This is done via simple and low-cost phase inversion membrane fabrication techniques developed within our labs. The blackbody-like membranes we develop should poses high thermal conductivity, which is the other objective we focus on in this investigation.

4. Materials and methods

4.1. Materials

Polyvinylidene fluoride (PVDF) polymer (HSV900, Mw 92,840 kDa, Arkema, Colombes, France), dimethylacetamide (DMAC, Sigma-Aldrich, St. Louis, NA, USA) as a solvent, deionized (DI) water as the polymer and non-solvent, non-woven support (Novatexx 2471, donated by Freudenberg-filter, Weinheim, Germany), activated charcoal and graphene nanoplatelets.

4.2. Membrane preparation

4.2.1. AC and graphene nanoplatelets membranes

In a typical synthesis, PVDF (12 g) was first dissolved in dimethylacetamide (DMAC) under magnetic stirring to obtain a clear homogeneous solution. AC was added under magnetic stirring and ultrasonication to obtain a clear homogeneous solution. Then, the polymer solution was cast on a non-woven support at room temperature using a doctor blade with adjustable height to give a wet-casting thickness of 500 µm, which was immediately immersed in a coagulation bath of deionized water at 20°C. Finally, the membranes were dried in vacuum oven at 60°C for 24 h. The mass of AC used were 7, 9 and 12 g. A number of membrane samples were prepared via phase inversion which was similar to the AC membrane preparation but by replacing the AC by graphene nanoplatelets. The mass of graphene nanoplatelets used were 7, 9 and 12 g.

4.2.2. CNT membranes

Using the mass balance to measure the required amount of CNT and PVDF depend on the sample's concentration of PVDF, with a constant total mass of 800 mg for all the samples. Then, dissolve the CNT and PVDF in a mortar with 50 mL of the mixture of DI water and ethanol, then grind with a pestle for 2 min. Pour the 150 mL of DI water and ethanol in a beaker with grinded CNT and PVDF with magnetic stirrer. The solution was mixed under magnetic stirring and sonicated to obtain a clear homogeneous solution for 15 min. Then, the solution was cast on a copper sheet using a doctor blade with thickness of 5 mm. Finally, the membranes were dried in oven at 120°C for 1 h.

4.2.3. Chemical vapor deposition

To fabricate our envisioned solar absorbing membranes, we developed a flat-sheet membrane via chemical vapor deposition., we use anodised aluminium oxide membranes as the base material and grown high absorbance blackbody like multilayer three-dimensional graphene coating which grows on the top and bottom surface of the membrane and within the nanoporous structure.

4.3. Membrane characterization

The absorbance for each membrane was measured using a UV(vis) spectrometer. The structures of the prepared

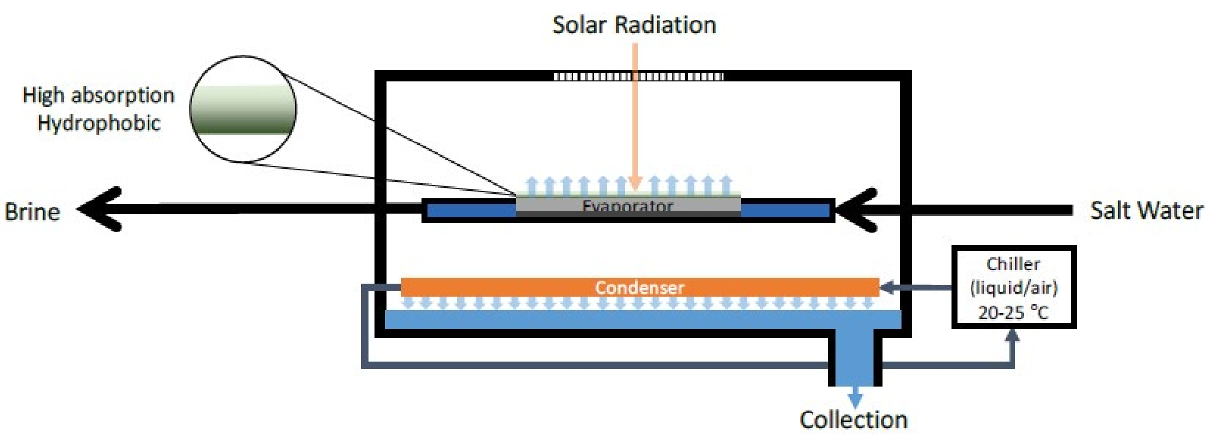


Fig. 1. Nanoporous evaporator based desalination device.

Fig. 2. CNT membrane fabrication.

membranes were characterized and observed by scanning electron microscopy (SEM) and atomic force microscopy. The mean flow pore size, bubble point pore size and pore size distribution were measured using a capillary flow porometer. Also, the porosity was calculated experimentally using a gravimetric method using Salwick as a wetting liquid. Contact angle measurements were also performed to know the hydrophobic/hydrophilic nature of the membranes.

4.4. Evaporation experiments

All membranes are tested in a device fabricated specifically for the purpose of this study (Fig. 3). The membranes are tested for their ability to evaporate seawater using direct sun light. Measurements of mass fluxes and temperatures are taken, and the overall efficiency of the device is calculated. This study aims at demonstrating these solar absorbing membranes as the core enablers for future direct solar desalination technologies.

5. Results and discussion

The contact angle (CA) measurement is a way to describe the hydrophobic or hydrophilic behavior of a material. In principle, it provides information about the wettability of an ideal surface. In most cases, the intrinsic value of

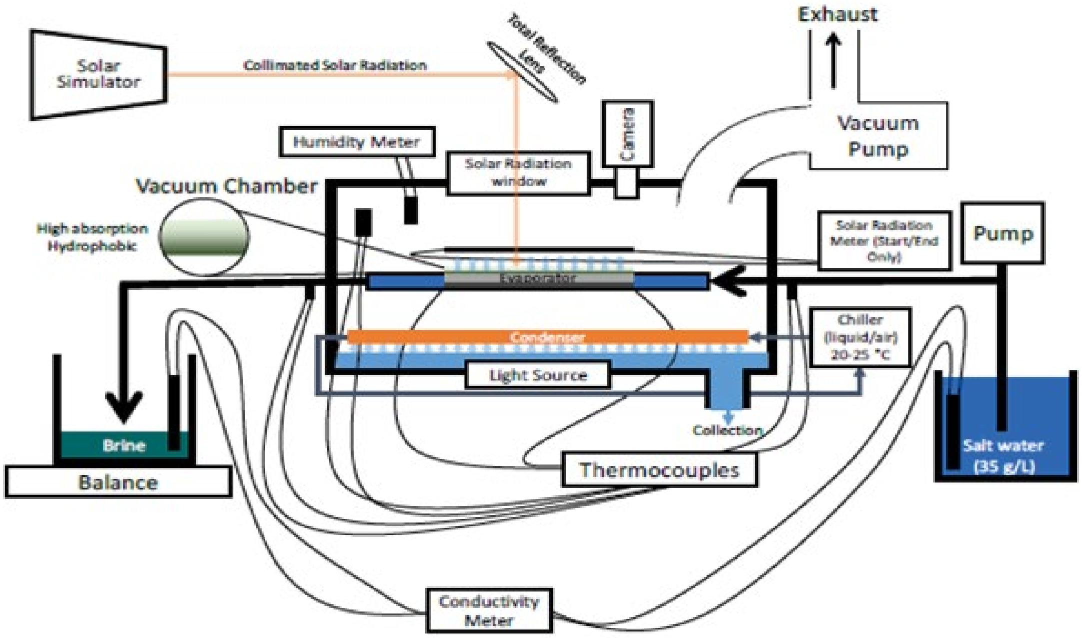


Fig. 3. Experimental setup for membrane characterization.

Table 1
Membranes properties with casting thickness of 500µm and PVDF concentration of 12% (w/w)

Chemicals	Mass (%)	CA (°)	Porosity (%)	Absorbance (%)
PVDF	12	95.5	28.6	9.1
Activated carbon	7	83.6	31.91	94.39
	8	81	34.91	94.40
	11	74	40.21	95.33
Graphene	7	74.6	29.02	96.29
	8	68.6	35.98	97.25
	11	66	45.41	97.99

contact angle is perturbed by surface porosity and roughness, heterogeneity, etc. (Drioli et al. 2006).

If the affinity between liquid (droplet) and solid is low on a smooth surface is greater than 90°m the material is considered hydrophobic (Drioli et al. 2006).

The contact angle measurements for the AC and graphene membranes with different rates of mass found that for each membrane, the contact angle decreases with the increase of the activated carbon and graphene percentage in the membrane. However, the contact angle of CNT increases as PVDF% increase and it seems all are hydrophobic.

The absorbance of AC, graphene and CNT membranes were measured using a UV(vis) spectrometer.

5.1. Scanning electron microscopy

The microstructures and morphologies were characterized by field emission scanning electron microscope. The SEM observations of the membrane samples and the samples were mounted with conductive glue to metal stubs and

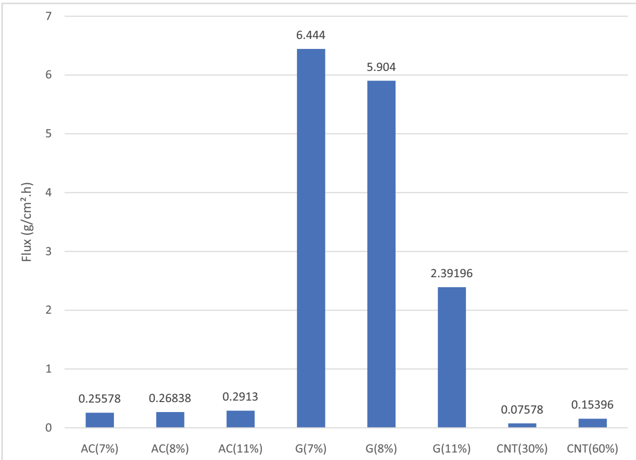
Table 2
Membranes properties of CNT

Chemicals	PVDF (%)	CA (°)	Porosity (%)	Absorbance (%)
CNT	30	103.9	32.23	95.5
	45	115.18	22.92	94.9
	60	104.25	20.94	94.4
	75	108.1	19.44	94.2

then coated with gold by sputtering. These samples were then viewed in the SEM at different magnification.

SEM images of the PVDF membranes with different percentages of activated carbon and graphene nanoplates are shown in Figs. 4 and 5.

5.2. Flux result from evaporation experiment



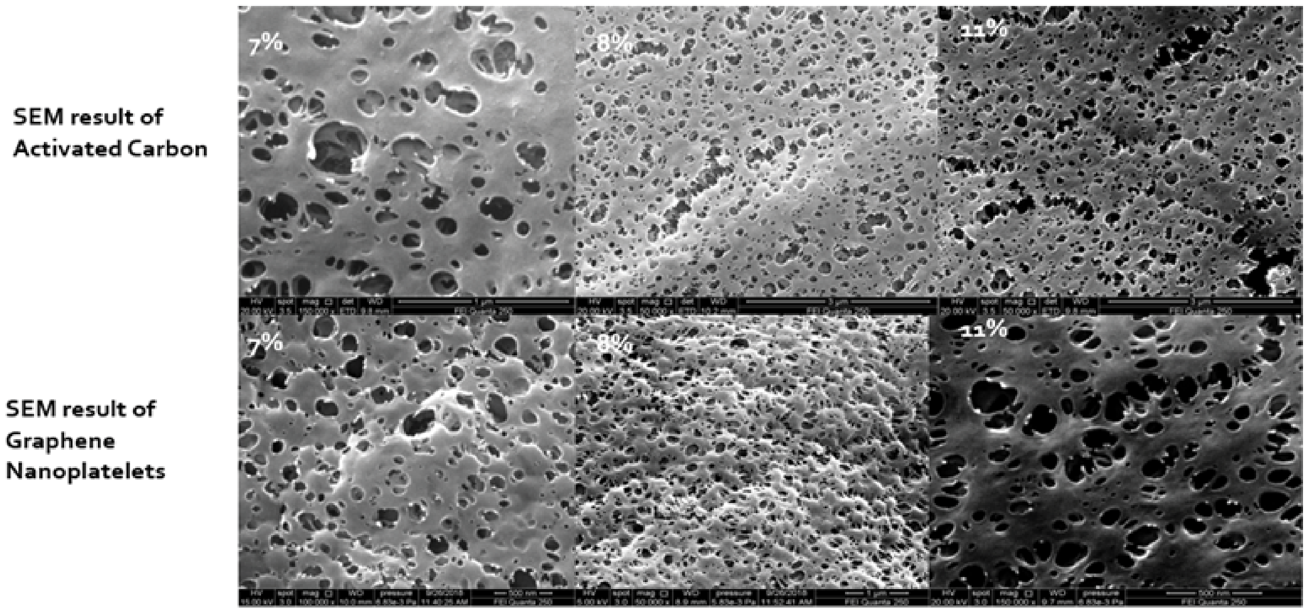


Fig. 4. SEM photo of AC and graphene nanoplates.

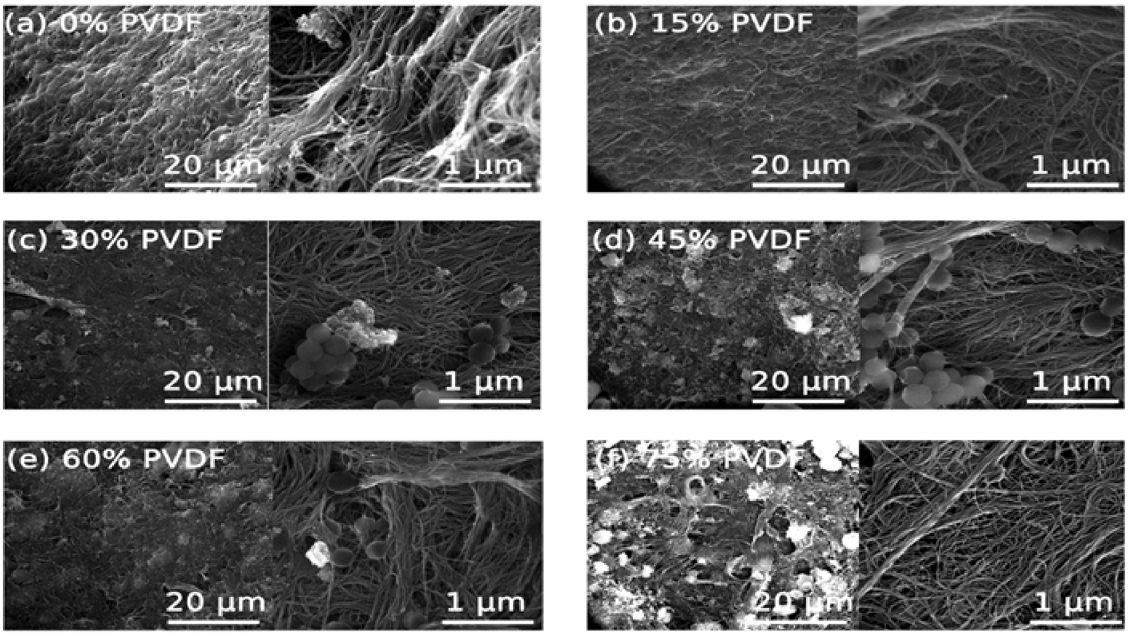


Fig. 5. SEM photos of CNT membranes.

6. Conclusion

As a results, from CNT membranes, the absorption and the porosity increase as the PVDF concentration decreases while the contact angle increases as the PVDF concentration increases. The contact angle measurements for the AC and graphene membranes with different rates decrease with the increase of the activated carbon and graphene percentage in the membrane. Also, it was found from SEM that activated carbon can enhance considerably the porosity of the membrane. The contact angle and the hydrophobic characteristic decrease with the increase of the activated carbon concentration in the membrane. Graphene membranes resulted in high evaporation flux. The complete set of results and the result of evaporation experiment will be analysis and be included in the full submission.

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