Carbon Nanotube Immobilized Membranes for Next Generation Desalination

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ABSTRACT

The objective of this project is to utilize carbon nanotubes (CNTs) to create breakthrough membrane properties for the generation of pure water via membrane distillation (MD). This fundamentally new approach will reduce the cost and energy requirements for the utilization of waste and brackish water and will dramatically change the competitive landscape of conventional methods such as Reverse Osmosis (RO) and thermal evaporation. Also, MD can be operated at relatively lower temperatures (60-90^{o}C) using low-grade heat. This makes feasible the possibility of utilizing waste heat and alternative energy sources such as solar energy. The use of electrical energy is minimal.

The novel membrane referred to as carbon nanotube immobilized membranes (CNIM) are developed by immobilizing CNTs into membrane pores where, they serve as molecular transporters and sorbents, thus providing additional pathways for solute transport. The CNTs also increase the functional surface area due to their high aspect ratio. All of these mechanisms play important roles in the transport of water vapors and lead to enhanced performance desalination

Keywords: Carbon nanotube, Membrane, Desalination, Membrane distillation

1 INTRODUCTION

Membrane Distillation (MD) is a thermal evaporative process that offers several advantages over traditional methods. Since operations in MD are at relatively low temperatures (60-90^{o}C), it is particularly attractive for the production of high purity water. Because of lower energy requirement, MD can potentially be operated effectively using low grade heat sources that have previously been generated for example in power plants, chemical, food and other industries. It can also be run on solar energy. In essence, MD can operate as a near "zero-cost" energy technology and it will not contribute to global warming because with the exception of some electricity no additional fossil fuels are consumed in generating heat.

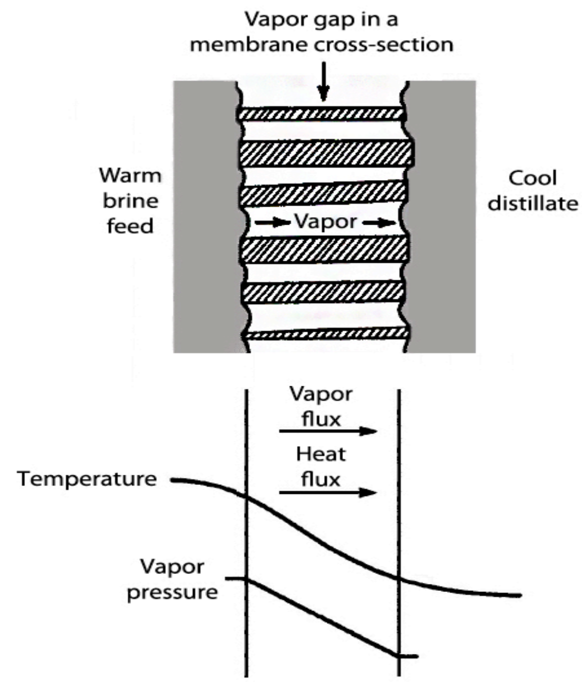

Figure 1: MD - Driven by Temperature and Water Vapor Pressure Gradients

2 CARBON NANOTUBE IMMOBILIZED MEMBRANE (CNIM)

We have utilized carbon nanotubes (CNTs) to create breakthrough membrane properties for the generation of pure water via MD. The novel membrane referred to as carbon nanotube immobilized membranes (CNIM) are developed by immobilizing CNTs into membrane pores where, they serve as molecular transporters and sorbents, thus providing additional pathways for solute transport. Immobilizing the CNTs in the pores alters the water-membrane interactions, which is one of the major physicochemical factors affecting the permeability and selectivity of the membrane [1]. Since CNTs are highly hydrophobic, they decrease the tendency of a pore to become wet with liquid, so higher transport of pure vapor can occur. The CNTs are known to have rapid sorption and desorption capacities leading to rapid mass transfer, and it is also possible that they allow the water vapor molecules to follow a surface diffusion pattern in which the solute hops from one site to another by interacting with the surfaces. This increases overall vapor transport [2]. The CNTs may also provide an alternate route for fast mass transport via diffusion along their smooth surface, as well as be transported directly through the inner tubes of the CNTs, which are known to enhance vapor transport. The CNTs also increase the functional surface area due to their high aspect ratio.

It is worth mentioning that the amount of CNTs is so small enough that they do not increase the thermal conductivity of the membrane or cost.

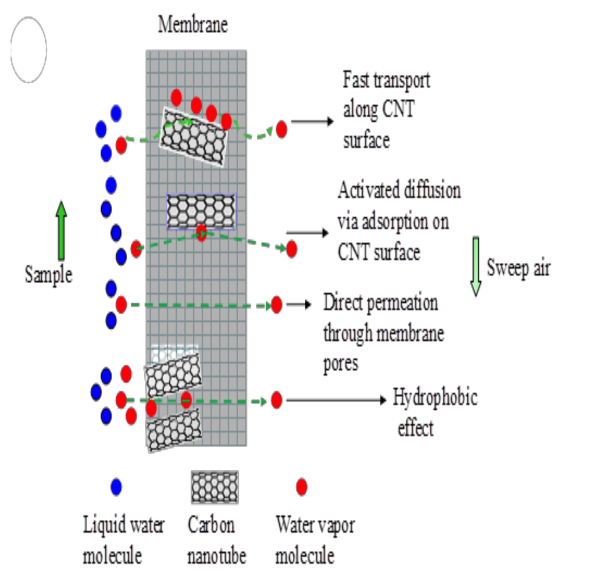

Figure 2: Mechanisms of MD in the presence of CNTs

All of these mechanisms play important roles in the transport of water vapors and lead to enhanced performance in MD. Results to date show 165% enhancement in flux [3]. The CNIM is fabricated based on a scalable approach developed in our laboratory. So far our work with sea water to produced water from hydraulic fracturing show excellent results with salt concentrations as high as seven times that of sea water.

3 ADVANTAGES OF CNIM

This fundamentally new approach will reduce the cost and energy requirements for the utilization of waste and brackish water and also treating produced water from hydraulic fracturing. This will dramatically change the competitive landscape of conventional methods such as Reverse Osmosis (RO) and thermal evaporation. MD offers several advantages over RO including the ability to handle higher salt concentrations, less stringent pretreatment requirements, less energy consumption, significantly less fouling and longer lifetime for the membranes. The method can also be effectively used to treat RO reject. Some advantages of CNIM-MD over Ro is listed below:

CNIM-MD	RO
Recovery of CNIM-MD ~90%	Recovery of the seawater RO 35 - 45%
Can handle high salt concentration including RO reject; requires significantly less feed pretreatment	Osmotic and operating pressure increases with salt concentration; high pretreatment cost
Operate at one atmospheric pressure	Typical operating pressures between 100-225 psig
Primary energy use in CNIM-DCMD is to heat the feed water (60-90^{o}C); waste heat utilization reduces/eliminates that cost	The primary energy requirement is for operating high pressure pumps
Less fouling of membrane with high porosity	Dense nonporous membrane prone to fouling
Higher temperature significantly reduces bio-fouling	Significant bio-fouling
Longer membrane life time >5 years	Short life time, typical 5 years

Table 1: Advantages of CNIM-MD over RO:.

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