

A Review on Recent Developments in Desalination by Forward Osmosis (FO) and Reverse Osmosis (RO)

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Abstract: *Osmosis is a physical phenomenon in which solvent molecules move through a semipermeable membrane from a dilute solution towards more concentrated solution. Initially, the mechanism of osmosis through natural materials was studied but now a days scientists have given special attention to osmosis via synthetic materials. Osmosis, or as it is currently referred to as Forward Osmosis (FO), has new applications in separation processes for wastewater treatment and seawater/brackish water desalination. Reverse Osmosis (RO), a process by which a solvent passes through a porous membrane in the direction opposite to that for natural osmosis when subjected to a hydrostatic pressure greater than the osmotic pressure. is currently the most important desalination technology and it is experiencing significant growth.*

I. Introduction

Providing clean and affordable water to meet human needs is a grand challenge of the 21st century. Worldwide, water supply struggles to keep up with the fast growing demand, which is exacerbated by population growth, global climate change, and water quality deterioration^{1,2,3,4}. In recent decades, increased domestic, agricultural and industrial activities worldwide have led to the release of various pollutants, such as toxic heavy metals, inorganic anions, organics, micropollutants and nutrients into the aquatic environment. The removal of these wide varieties of pollutants for better quality of water for various activities is an emerging issue and a robust and eco-friendly treatment technology is needed for the purpose. It is well known that cellulosic materials can be obtained from various natural sources and can be employed as cheap adsorbents⁵. In recent years, semiconductor photocatalytic process has also shown a great potential as a low-cost, environmental friendly and sustainable treatment technology to align with the “zero” waste scheme in the water/wastewater industry. The ability of this advanced oxidation technology has been widely demonstrated to remove persistent organic compounds and microorganisms in water. At present, the main technical barriers that impede its commercialisation remained on the post-recovery of the catalyst particles after water treatment⁶.

Osmosis through asymmetric membranes has been studied as a means of desalination via forward osmosis and power generation through a process known as pressure retarded osmosis. The primary obstacle to using asymmetric membranes for osmotic processes is the presence of internal concentration polarization, which significantly reduces the available osmotic driving force⁷. The emergence of nano-technology in membrane materials science could offer an attractive alternative to polymeric materials⁸. Cellulose acetate (CA) nanofiltration (NF) hollow fiber membranes have been fabricated and tested in the forward osmosis (FO) process. A two-step heat-treatment, i.e., 60 min at 60 °C and 20 min at 95 °C, effectively shrinks the membrane mean pore radius from 0.63 to 0.30nm. The molecular weight cut off (MWCO) of the resultant CANF membrane is 186Da. In the NF experiments under 1bar transmembrane pressure, the newly developed CA NF membrane shows a pure water permeability (PWP) of 0.47 Lm⁻²bar⁻¹h⁻¹ and rejection levels of 90.17% to NaCl and 96.67% to MgCl₂⁹. The design and engineering of membrane structure that produces low salt leakage and minimized internal concentration polarization (ICP) in forward osmosis (FO) processes have been explored in this work. The fundamentals of phase inversion of cellulose acetate (CA) regarding the formation of an ultra-thin selective layer at the bottom interface of polymer and casting substrate were investigated by using substrates with different hydrophilicity. An in-depth understanding of membrane structure and pore size distribution has been elucidated with field emission scanning electronic microscopy (FESEM) and positron annihilation spectroscopy (PAS). A double dense-layer structure is formed when glass plate is used as the casting substrate and water as the coagulant. The thickness of the ultra-thin bottom layer resulted from hydrophilic–hydrophilic interaction is identified to be around 95nm, while a fully porous, open-cell structure is formed in the middle support layer due to spinodal decomposition. Consequently, the membrane shows low salt leakage with mitigated ICP in the FO process for seawater desalination¹⁰. With the aid of positron annihilation lifetime spectroscopy (PALS), the similarity in physicochemical properties between the polymer and the substrate was found to play a significant role in determining the porosity of the bottom interfacial layer. The structure of the dense interfacial layer was also strongly dependent on membrane thickness and solvent composition. Experimental results surprisingly reveal that the original pore size of the as-cast membrane plays a

critical role determining the final performance of the subsequent annealed membrane independently of annealing temperature and time¹¹.

With the rapidly increasing demands on water resources, fresh water shortage has become an important issue affecting the economic and social development in many countries. As one of the main technologies for producing fresh water from saline water and other wastewater sources, reverse osmosis (RO) has been widely used so far. Reverse osmosis membrane technology has developed over the past 40 years to a 44% share in world desalting production capacity, and an 80% share in the total number of desalination plants installed worldwide. The use of membrane desalination has increased as materials have improved and costs have decreased. Today, reverse osmosis membranes are the leading technology for new desalination installations, and they are applied to a variety of salt water resources using tailored pretreatment and membrane system design. Two distinct branches of reverse osmosis desalination have emerged: seawater reverse osmosis and brackish water reverse osmosis¹². A seawater desalination process separates saline seawater into two streams: a fresh water stream containing a low concentration of dissolved salts and a concentrated brine stream. The process requires some form of energy to desalinate, and utilizes several different technologies for separation. Two of the most commercially important technologies are based on the multi-stage flash (MSF) distillation and reverse osmosis (RO) processes¹³. However, a major challenge facing widespread application of RO technology is membrane fouling, which results in reduced production capacity and increased operation costs. Till date polymeric membranes have dominated the RO desalination industry. From the late 1950s to the 1980s the research effort focussed on the search for optimum polymeric membrane materials. With the aid of positron annihilation lifetime spectroscopy (PALS), the similarity in physicochemical properties between the polymer and the substrate was found to play a significant role in determining the porosity of the bottom interfacial layer¹⁴. In subsequent decades the performance of RO membranes has been optimised via control of membrane formation reactions, and the use of poly-condensation catalysts and additives. Nevertheless, the advances in membrane permselectivity in the past decade has been relatively slow, and membrane fouling remains a severe problem. Reverse osmosis membranes processing natural and waste waters are often exposed to low concentrations of chlorine in feed water. This biocide is chemically aggressive toward most commercial high performance membrane polymers. Chemical attack by chlorine ultimately results in membrane failure as measured by enhanced passage of both salt and water¹⁵.

In comparison to the ordinary forward osmosis process, the ultrasound-assisted forward osmosis process resulted in higher water fluxes in case of sweet lime juice as well as rose extract containing anthocyanin. The degradation of rose anthocyanin due to ultrasound was found to be 1.82%¹⁶. Forward osmosis (FO) has attracted attention in industry because of its low energy consumption and low fouling tendency¹⁷. Pressure assisted forward osmosis (PAFO) was used instead of FO to increase the water production rate. It had been found that water production in PAFO was increased by 9% and 29% at applied pressure of 2 and 4 bars¹⁸. A new Forward osmosis-Electrodialysis-Reverse osmosis (FO-ED-RO) hybrid system employs FO element upstream to ED-RO system for an access to draw solutions with higher electrical conductivity, aiming at reducing energy consumption and inheriting various advantages of ED system¹⁹. Forward osmosis (FO) nowadays considered a breakthrough technology that can be potentially used for concentrating suspensions and solutions, including wastes such as sewage. The sewage concentration by FO represented a habilitating technology enabling the application of a wider range of treatment alternatives²⁰. The membrane flux increased by 93.3% due to temperature increase from 20 to 26 °C and the flow rate from 1.2 to 3.2 L/min using a 0.5 M NaCl solution as the draw solution and distilled water as the feed solution (FS)²¹. High permselectivity of osmosis based on nanocomposite of mesoporous silica nanoparticles and nanofibers by electrospinning were analysed²².



Fig.1 The Third River in Iraq

Osmosis played an important role in providing good water quality at Iraq. Around 150,000 km² of Iraqi agricultural lands drain into by the Main Outfall Drain, formerly called The Third River, shown in Fi.1. The MOD is situated between the Tigris and Euphrates Rivers, and passes through the main Mesopotamian marshlands south of these rivers. According to the Iraqi Ministry of Agriculture, the river has suffered from very high salt concentrations since it was constructed in 2008. It has a length of 565 km from north of Baghdad to the Arabian Gulf with the total discharge of 210 m³/s. Drainage water is released into Shat AL Basra canal and then flows into the Arabian Gulf. The salt rejection can be reduced from 97% to 88% to obtain high quantities of fresh water with an agriculturally acceptable (lower quality) by osmosis²³.

Salt rejection coefficient is an appropriate measure for the selectivity of a membrane when chosen for osmosis. The amount of RO concentrate waste water requiring disposal must be as minimal as possible (near zero-discharge); the recovery of high quality water should be as high as possible^{24,25}. Membrane solids is a complex phenomenon involving the deposition of several types of solids on the membrane surface. If it occurs, the permeability of the RO membrane lowered, which in turn affects the energy requirement²⁶. RO has been used widely for various water and wastewater treatment processes, in areas with scarce water supplies (as a means of sea-water desalination) and importantly for this study the treatment of brackish water^{27, 28}.

The benefits of reverse osmosis are its small footprint, a modular design and the possibility of automatic process control and relatively low cost of water production²⁹.

Other unique benefits of forward osmosis include pressure-retarded osmosis for generation of electricity from saline and fresh water and implantable osmotic pumps for controlled drug release beside utilisation in separation of pure water in water treatment³⁰.

II. Conclusion

Forward osmosis (FO) has attracted growing attention in many potential applications such as power generation, desalination, wastewater treatment and food processing. However, there are still several critical challenges, including concentration polarization, membrane fouling, reverse solute diffusion and the need for new membrane development and draw solute design in FO.

The field of RO membrane desalination has rapidly grown and Membrane technology has improved, allowing significant increases in product production and cost savings. RO recovery is primarily limited by osmotic pressure increase and organic material fouling. However further improvements in membrane technology will allow a wider application of RO to inland and rural communities.

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