Membrane Distillation And Forward Osmosis Technologies Of Water Purification

The 21st century has been named the ‘‘Century of the Environment” to properly emphasize the critical environmental issues. Water scarcity is perhaps the most important environmental challenge, which is a global risk to not only the economic development but also the food security. Despite the fact that the Kingdom of Saudi Arabia has one of the largest oil reserves in the world, severe water scarcity along with other environmental concerns is making vital challenges for further investments. In recent years, much of the land that could be available for food production has been destroyed through increasing desertification. Given the fact that ubiquitous seawater is readily accessible in these regions, membrane-based desalination technology is considered as a promising means to effectively combat growing water issue.

Compared to all other purification methods, some of the advantageous features including low cost, high energy efficiency and ease of operation make membrane-based techniques more attractive for commercial applications. This kind of processes are irreversible, which usually do not provide any description of the phenomenon at the molecular level. To further reduce the cost of existing membrane technologies, it is necessary to focus on what makes current technologies expensive. Energy is undoubtedly the most significant contributor to the cost of desalination. Therefore, reduction in energy usage is the primary objective to ensure wider commercial applications of membrane-based desalination technologies.

In recent times, the investigation on forward osmosis (FO) compared to other membrane based desalination technologies has gained massive interest in both academic and industrial sectors. Unlike pressure-driven membrane processes, such as reverse osmosis (RO), osmotic pressure difference is utilized to drive water across a semipermeable membrane in the FO method. In this kind of naturally occurring process, the predesigned concentrated draw solution (DS) with high osmotic pressure can extract water from the dilute feed solution (FS) like seawater. Meanwhile, the embedded membrane between DS and FS can reject almost all other unwanted solutes as well. The important advantages of FO over other desalination processes could be listed as higher rejection of pollutants, lower membrane fouling, and better performance of water recovery. The overall energy consumption in a FO process may also be minimized by using a high efficiency DS that can be readily regenerated.

On the other hand, Membrane distillation (MD) is a non-isothermal separation process in which only volatile molecules of water are provoked to pass across a porous hydrophobic membrane and non-vapor solutes are fully retained in the feed side. This separation process works based on the principle of vapor pressure difference between feed and permeate sides. The vapor pressure of volatile solvent is raised by increasing the temperature of feed solution. In contrast, the temperature in permeate side is kept lower than feed side to control its vapor pressure. The difference of vapor pressure between two sides of membrane leads to the evaporation of water molecules at the liquid-vapor interface. The hydrophobic (non-wetting) membrane allows only the vapor to pass through it, while water in liquid form is retained. In the MD system, there is no need to boil feed water, meaning that it can work in moderate temperatures. This could effectively decline total energy consumption of a MD desalination system and make it a better option to commercialize.

The membranes are the main part of FO and MD desalination systems and can significantly influence their overall performances. Therefore, the lack of effective membranes has hindered the development and application of FO and MD processes in practice. The FO water flux is usually lower than the theoretical value regardless of membrane or draw solution characteristics, which has been related to internal concentration polarization (ICP) effect of membrane. To minimize the unpleasant ICP effect, a lower value of the structural parameter (S = thickness × tortuosity/porosity) of FO membrane is preferred. A smaller S value might be achieved by constructing lower tortuosity, higher porosity and thinner structure of support. Previous researches demonstrated that thin substrates with needle-like straight pores have significantly lower S value compared to conventional sponge-like pore structures.

About MD technology, it should be mentioned that the existence of non-isothermal liquid transport through membranes was first described by Lippman in 1907. In 1963, the first patent on MD was recorded by Bodell, whereas the first scientific paper on this kind of separation process was made by Findley four years later. However, the interest on MD faded quickly afterwards mainly due to the unavailability of adequate membranes to conduct this process. Interestingly, an explosion of MD applications took place after the discovery of porous polytetrafluoroethylene (PTFE, Teflon) membrane. To achieve the highest performance, the MD membranes should be made very hydrophobic, thin and porous. As an effort, nanofibrous electrospun membrane was fabricated and subsequently used in MD desalination process. Despite many advantages of electrospun membranes over conventional membranes, lower solutes rejection as well as exacerbated mechanical stability are the main concerns hindering their large scale applications. The pore size of the membrane and its distribution are critical factors, which determine the effectiveness of MD membranes to separate water from other dissolved components. The pore size may vary from several nanometers to few micrometers. While developing a membrane, it should be kept in mind that smaller pores restrict water transportation resulting in lower water flux. It is also better to fabricate a membrane with a narrow pore size distribution, meaning that the maximum pore size should be close to the mean pore size. In this way, the risk of pores getting wet would be appropriately controlled by different mechanisms of water flow. The enhancement of porosity would also contribute to the membrane’s mechanical stability and integrity. Furthermore, the higher entrapped air in a porous membrane could provide a better thermal insulation against heat transfer from hot feed side to cold permeate side.

To get more improved FO and MD desalinations, the utilized membranes need to be structurally engineered in which higher porosity with uniform pore dimensions would be achieved. Templating via different emulsions and nanostructured compounds is a novel technique to modify the matrix of polymeric membrane as desired. Depending on 3D structure and concentration of templating material, different pore’s morphologies with specific structure and distribution could be formed in FO and MD membranes. Furthermore, both FO and MD technologies suffer from some bottlenecks when they are working individually. For instance, the DS has to be regenerated after getting diluted in a FO unit. It could be simultaneously done by a combined MD unit. So far, a few researches have been conducted on hybrid FO-MD process.