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Pervaporation: An Emerging Technology for Desalination

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Water shortage is a worldwide problem which leads to rapid developments in technologies targeting waste water reclamation and seawater desalination. Currently, reverse osmosis (RO) appears to be the most efficient way for producing fresh water from seawater with an average salinity of 3.5 wt% and brackish water with a salinity of 0.05-3 wt% mainly due to its low cost and high salt rejection over 99.5%. However, the driving force for RO process is the pressure difference between the feed and permeate sides of the RO membrane. To overcome the osmosis pressure, a very high feed pressure is mandatory to be able to squeeze water from concentrated salt solution. Therefore, a typical water production rate is only 50% for seawater RO desalination process. It not only limits the productivity of RO, but also produces high concentrated seawater that may cause seriously environmental issues.

To address this problem, novel membrane technologies are proposed to increase the water production rate. Membrane distillation (MD) may be a solution since the driving force of this technology is the water vapor partial pressure difference. In this case, water can be separated from highly salty water if apply vacuum or cooling water in the membrane permeate side. However, membranes applied in MD process need to be hydrophobic which makes them suffering severe fouling problem. In addition, the formation of NaCl crystal in the membrane surface may also deteriorate the separation efficiency. Although many research works have been done to solve these two issues, to my best knowledge there is no real industrial applications for MD desalination.

Recently, few research groups including us start exploring the possibility of using pervaporation (PV) membranes for seawater desalination. The separation mechanism of PV is solution-diffusion which is similar to RO but different from MD. Specifically, a liquid mixture first absorbs on the feed side of the PV membrane and then diffuses across the membrane and subsequently desorbs at the permeate side. Due to the different solubility and diffusivity of each component of the liquid mixture in the membrane material, the PV membrane is able to selectively permeate one component over others to separate the mixture. Similar to MD process, the driving force can be supplied by applying vacuum or sweep gas in the permeate side. Hence, high concentrated salt solution can be dehydrated. Right now, PV technology has been industrially applied in organic solvent dehydrations, and removal of volatile organics from aqueous solutions. In both processes, the separated matter is the minor part of the mixture. Therefore, the membrane flux needs not to be very high. For instance, a typical water flux for a PV dehydration membrane ranges from 100-1000 g/(m^2·h). Since the water fluxes of RO and MD processes are 60-70 L/(m^2·h), it seems that PV is not a practical technology for desalination. However, consider that the water concentration in the liquid mixture for dehydration processes is normally less than 5 wt%, while in seawater desalination process the water concentration is higher than 90 wt%. If applied a PV membrane in desalination, the water vapor driving force would be 20 times higher. In addition, the PV membrane material would be swelled by the high concentrated water solution; therefore the water flux could be further increased. Note that, retentates such as salts are non-volatile with relatively large molecular size compared to water molecule. The swelled PV membrane can still achieve good rejection to them. Therefore, applying PV membrane for desalination may obtain good salt rejection with impressive water flux. Our group has fabricated several PV membranes, and the highest water flux among them is 65.1 L/(m^2·h) at a temperature of 90°C with a NaCl rejection of 99.8% for seawater desalination. This performance is very promising and comparable to RO and MD processes.

