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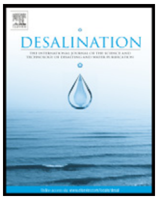

Desalination by pervaporation: A review

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HIGHLIGHTS

- The feasibility of water desalination by pervaporation was reviewed.
- The mechanisms of mass transport and rejection were comprehensively discussed.
- Detailed information on membrane preparation, structure and performance was summarized.
- The effects of operating conditions on PV performance were thoroughly analyzed.
- Future research needs on membrane materials for PV desalination were recommended.

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ABSTRACT

Desalination via pervaporation has the potential to be an efficient way of getting fresh water from non-potable saline sources with the advantages of a high rejection of salt and the capability of coping with high-salinity solutions. This overview of desalination via pervaporation mainly focuses on membrane materials, transport mechanisms and the effect of operating parameters on PV performance. Almost all kinds of membranes ever reported in desalination are mentioned, including those based on polymers, inorganic materials and their hybrids, all of which show reasonably performance with adequate flux and excellent salt rejection. The comparison of pervaporation with existing conventional reverse osmosis and membrane distillation processes and several strategies for further improvement of pervaporation performance are discussed.

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1. Introduction

With the rapid increase in global population and urbanization, water scarcity is becoming one of the major challenges of contemporary society. Numerous initiatives are under way to find engineering solutions to improve potable water supply. Desalination technology is an efficient way of solving the problem. It works by selectively removing salt from non-potable saline sources such as brackish (1–10 g/L), sea (35 g/L) and brine (75–150 g/L) [1–4]. Membrane technology is now universally accepted as an attractive solution for desalination because of its high efficiency and potential energy savings compared with traditional distillation techniques [5,6]. In addition, it has many advantages such as high operational stability, low chemical costs and ease of integration and control within industrial process trains [6]. Reverse osmosis (RO) is currently the most mature membrane technology for desalination at a relatively low cost [7,8]. Approximately 60% of desalination plants installed in the world are RO desalination plants [6]. RO is a process which allows the passage of water out of the solution with a mechanical pressure greater than the osmotic pressure of feed solution applied. Thus, RO must rely on the creation of a suitably high osmotic gradient across the membrane to achieve a reasonable flux. Novel membranes such as aquaporin membranes, nanocomposite membranes, carbon nanotube membranes and graphene-based membranes show superior performance with improved flux, chlorine tolerance and fouling resistance, but are still in the fundamental developmental stage [9,10]. In recent years, compared with pressure driven processes, non-pressure driven membrane processes like membrane distillation (MD) and pervaporation (PV) have become attractive in treating high total dissolved solids (TDS) source water and being more resistant to certain types of fouling [11].

MD is a thermally-driven separation process that has been studied comprehensively for desalination [12–19]. In MD, vapor molecules evaporate from the feed solution and are transported through micron-dimension pores (often ranging from 0.1 to 1 μm) of hydrophobic membranes as distillate. The driving force in the MD process is the vapor pressure difference induced by the temperature difference across the membrane. The hydrophobic MD membranes are fabricated typically from polytetrafluoroethylene (PTFE), polypropylene (PP), polyethylene (PE) or polyvinylidene fluoride (PVDF) materials. An MD membrane provides shorter paths and larger available interfacial area for mass transfer between two phases (liquid–liquid or liquid–gas) than a traditional evaporator, allowing an efficient and easily controlled operation. When the permeable side (often pure water) is in direct contact with the membrane, the MD is known as direct contact membrane distillation (DCMD) which is a most widely used configuration. In other cases, the vapor phase is condensed by an air gap from the membrane (AGMD) or separated by a vacuum (VMD) or a sweep gas (SGMD). Using MD has many attractive features, such as a theoretical 100% rejection of ions, macromolecules, colloids, cells, and other non-volatiles which can be reached in a single step based on the principle of vapor–liquid equilibrium, being conducted at lower operating temperatures than conventional distillation and under lower operating pressures than pressure-driven membrane processes such as RO. MD is usually carried out at a temperature of 50–90 °C, which makes it possible to utilize low grade heat such as conventional solar energy, geothermal and waste heat. Therefore, MD may be competitive with RO when low cost heat energy is available. However, it has been observed that the hydrophobicity of MD membrane may decrease resulting in the reduction of permeate flux and the loss of salt rejection due to the wetting of membrane surface during prolonged use [20,21]. Membrane wetting can occur when the hydraulic pressure applied on the surface of the membrane is greater than the minimum liquid entry pressure (LEP) of the membrane, which can be quantified by the Laplace equation [12,22]. Details on the significance of the LEP and its effect on membrane wetting have been published [23]. Moreover, the presence of any non-polar such as alcohols or surface-active molecules in the feed solution and the deposition of foulant such as salt crystals on the membrane surface will seriously reduce the hydrophobicity of the membrane and thus increase the chance of membrane wetting [23–27]. Membrane fouling and wetting are recognized as challenging problems in MD that can cause major damages and increased costs of the process especially for long term operation [20,21].

PV is another membrane process which has attracted increasing interest as a potential desalination method. In PV, certain components in the feed solution preferentially permeate through a dense or molecular- sieving porous membrane and evaporate downstream. The driving force in PV for the mass transfer of permeate is the chemical potential gradient between the feed side and permeate side of the membrane. In contrast to its emerging application in desalination, PV has been well known in application to separate liquid mixtures, such as dehydration of organic solvents, evaporation of volatile organic compounds from aqueous solutions, and separation of mixed anhydrous organic mixtures. Currently, dehydration of alcohols and other solvents and removal of small amount of organic compounds from contaminated water have been relatively well understood and successfully utilized in full-scale industrial production [28–30]. In the separation of an aqueous-organic mixture or an organic–organic mixture, two main areas of PV can be identified: hydrophilic PV and organophilic PV (that is, hydrophobic PV), depending on the target compound separation and specific application. The target compound is water in the first case and organic component in the second case. For desalination purposes, PV involves a hydrophilic dense polymeric membrane or molecularly porous inorganic membrane that is in contact with the feed salt solution on one side, while the target compound-water preferentially permeates and is removed as vapor from the opposite side. As shown in Fig. 1, desalination by PV is a combination of diffusion of water through a membrane and its evaporation into the vapor phase on the other side of the membrane to produce fresh water.

PV and MD are both membrane separation processes in which the upstream side of the membrane is in contact with generally hot feed liquid and certain components permeate through membrane due to the lower vapor pressure on the downstream side of the membrane. In both processes, a vapor difference is maintained across the membrane.