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Review

A mini-review on pervaporation membrane for desalination

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ABSTRACT

Water pollution, which leads to water scarcity, has become one of society's most challenging problems due to the increasing global population and urbanization. Desalination is a helpful strategy for dealing with water scarcity. Nowadays, reverse osmosis is the most common desalination technology. However, it requires energy to overcome osmotic pressures above 500psi. The high energy consumption and other challenges of seawater membrane desalination and strategies to reduce energy were reported elsewhere. Pervaporation (PV) has emerged as the membrane technology for desalinating seawater recently because of its benefits, which include high salt rejection, saving energy, and low fouling phenomena. Accordingly, the PV process can be considered a "green" technology. This study aims to give an overview of research that has employed PV in desalination. This is with an emphasis on PV membrane materials used in desalination and some PV concepts. Overall, the pervaporative desalination process is based on the solution – diffusion mechanism, in which the driving force of the separation process is basically the difference in the partial vapor pressure between the feed and permeate sides divided by the PV selective membrane. Polymer membranes are being studied extensively due to their easy preparation method, low cost, and good salt separation performance compared to organic membranes. To date, the research trend on mixed matrix membranes has gained considerable attention since the unique properties of inorganic fillers, and polymer matrix can be combined to provide resulting membranes with improved salt separation capabilities and stability at higher temperatures. Pervaporation has shown high promise for desalination with adequate productivity and high selectivity. Accordingly, many studies have been conducted in lab and pilot scales to develop the future PV process for commercialization on an industrial scale.

Key words: pervaporation, membrane, thin-film composite, filtration, desalination

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INTRODUCTION

The water crisis is a global problem due to population explosion, overuse, increasing demand, rising water pollution, and climate change. Freshwater makes up only 2.5% of all water on the planet; the rest is seawater[1]. Water scarcity affects 700 million people in 43 nations today. It is assumed that two-third of people in the world will lack clean water in 2025. Today, more than 150 countries use desalination in some form or another to address specific portions of global demand, providing drinking water to more than 300 million people[2]. To solve this, separating salt from brackish and sea water is an effective way to produce freshwater[3]. In 2018, 18,426 plants filtering salt from seawater were operating in approximately 150 countries. They have made about 87 million cubic meters of clean water per day, which could serve over 300 million people. Nearly half of this capacity (44%) is in the still-growing Middle East market, but other nations, such as China, the United States, and Latin America, are developing even faster[2].

Nowadays, reverse osmosis (RO) is usually used to remove salt from brackish and seawater to produce fresh water since it has been proven on a large scale with high rejection and flux. However, RO needs a high pressure above 500 psi, which is greater than the osmotic pressure derived from high salt concentration in seawater for producing freshwater. Pervaporation (PV) has become a well-known alternate membrane for desalination in recent years because it shows high selectivity, cheap energy, and high resistance to pollutants attaching to the membrane. The RO process produces greater water flow (30-60 kg.m^{-2}.h^{-1}) but consumes more energy (2-4 KWh.m^{-3}). In comparison, despite making less permeation (0.05–15 kg m^{-2}.h^{-1}), the PV process uses just 2 KWh.m^{-3}[4]. Notably, the critical role in deciding the separating performance of the PV process is the physicochemical properties and morphology of the membrane.

Therefore, several research projects have focused on finding appropriate materials for fabricating selective layers and enhancing the separation performance of derived membranes[5]. Pervaporation membranes are made from different materials, including polymers, inorganic materials, and composite or nanocom-

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posites, prepared by organic and inorganic components[6–8].

This paper seeks to study PV membranes for desalination over the previous years. It has a particular emphasis on membrane materials like as polymeric, inorganic, and mixed matrix membranes.

PRINCIPLE OF PERVAPORATION DESALINATION

PV membranes serve as a selection layer that separates a liquid-feed phase and a vapor permeation phase (Figure 1). The solution–diffusion theory describes PV's separation transport process. PV consists of three steps, including solution, diffusion, and evaporation. The partial vapor pressure of the feeding solution adjacent to the selective barrier is dissimilar to that of the permeation phase, resulting in the driving force in the PV process. In practice, PV is well-known for its use in liquid mixture separation, such as organic mixture separation and alcohol dehydration[9]. Water filtration is the goal of desalinating organic solvent dehydrating from solutions. Nevertheless, feeding characteristics differ. Water typically makes up less than 10% of the bulk solution for dehydrating organic solvents[6]. However, water makes up more than 90% of the feed for desalination. Accordingly, the membrane used for separating water from solvent is inappropriate for salt removal because it is easily swollen in water, adversely affecting the selectivity and even the life span of the membrane. One of the most significant challenges of utilizing traditional pervaporation membranes for desalination is their instability in solutions with large water proportions and when operating at high temperatures[10]. In the case of PV desalination, a membrane divides a solution at an ambient pressure comprising non-volatile salt and water molecules on one side and a vapor phase at a vacuum condition on the counter side. This procedure attends to the solution diffusion principle and includes three critical stages: (i) on the feed side, water molecules are absorbed onto selective layer membranes such as dense membranes (non-porous membranes) or very-finely-porous membranes; (ii) selective components diffuse through the membrane while non-volatile salts are retained; (iii) water molecules are desorbed via evaporation in the vapor phase onto the permeate side. Mass transfer in the selection layer relies on the dissimilarity in the concentration of permeating molecules in the feeding solution and permeate, their physicochemical characteristics, and the potential chemical gradient. The pervaporation process for desalination is depicted in Figure 1.

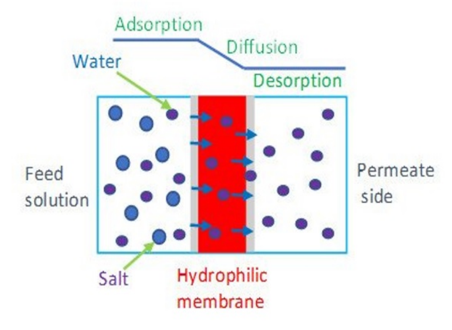

Figure 1: Mechanism of the PV process for salt removal[5]

Permeation flux (J) and salt rejection (R_s) describe the separation performance of PV membranes. Calculation of the J and R_s are shown in Eq. 1 and Eq. 2, respectively.

$$J(kgm^{-2}h^{-1}) = \frac{Q}{A \times t} \tag{1}$$

$$R_s\,(\%) = \left(1 - \frac{c_p}{c_f}\right) \times 100\% \tag{2}$$

Where A is the membrane's effective surface (m^2), t is the operating time (h), and Q is the permeate weight (kg). The salt content in the permeate and feeding solutions is C_p and C_f, respectively, which are measured by a conductivity meter.

MEMBRANES IN PV DESALINATION

At the moment, materials for PV membranes are mainly chosen based on personal experience; there are no established criteria for membrane material selection. Membranes have been made from a variety of materials in recent years, including polymeric, inorganic, and mixed matrix membranes. Table 1 shows some typical materials and the efficiency of the resulting membranes for salt removal.

Polymer based membranes

Polymer materials with remarkable selectivity are frequently the focus of intensive research in membrane fabrication nowadays. Although such a membrane has a low permeate flux, it can be significantly enhanced by adding asymmetry to the membrane morphology to narrow the selective layer using various manufacturing methods, such as interfacial polymerization, float-casting, and dip coating. Popular polymers used in fabricating PV membranes for desalination are polyether ester, polyamide, cellulose, cellulose acetate, poly(vinyl alcohol), etc.

Table 1: Some typical materials and performance of the resulting membranes for salt removal

Membrane	NaCl content	Temperature	Vacuum conditions	Flux (kg.m^{-2}.h^{-1})	Rejection (%)	Reference
Crosslinked PVA/PVDF hollow-fiber membrane	100 g.L^{-1}	80°C	vacuum 1 kPa	9	99.9	Li et al., 2017
GO/PI MMMs	3.5 g.L^{-1}	90°C	vacuum	36.1	99.9	Feng et al., 2017
Hybrid carbon-silica membrane	1 g.L^{-1}	60°C	vacuum	26.5	99.5	Yang et al., 2017
SiO_2@PVA/PSF hollow-fiber membrane	30 g.L^{-1}	70°C	vacuum	10.4	99.9	Chaudhri et al., 2018
GO/PDA-modified α-Al_2O_3 membrane	3.5 g.L^{-1}	90°C	vacuum	48.4	99.7	Huang et al, 2018
PMDA-crosslinked PVA on PAN microporous membrane	35 g.L^{-1}	70°C	vacuum	32.2	99.9	Zhang et al., 2018
MIL-53(Al)/crosslinked PVA hollow-fiber membrane	100 g.L^{-1}	80°C	vacuum 0.1 kPa	19	99.9	Liang et al., 2018
MXene-based membranes	3.5 g.L^{-1}	65°C	vacuum 0.4 kPa	85.4	99.5	Liu et al., 2018
S-PVA/Polyacrylonitrile membrane	35 g.L^{-1}	70°C	vacuum 100 Pa	27.9	99.8	Zhang et al., 2019
PVA/PVDF/PTFE membrane	3.5 g.L^{-1}	75.0 ± 0.9°C	DCPV mode	44.5 ± 3.0	> 99.9	Meng et al., 2019c
La/Y-organosilica membrane	3.5 g.L^{-1}	25°C	vacuum 0.6 kPa	10.3	99.99	Zhang et al., 2019
Sodium alginate-GO nanocomposite membrane	3.5 g.L^{-1}	60°C	vacuum	8.11	99.41	Nigiz et al., 2020
Silica/PVA hybrid membrane	3.5 g.L^{-1}	60°C	vacuum 1 kPa	12.3	> 99.9	Danielli et al., 2020
Al_2O_3/cellulose triacetate	30 g.L^{-1}	70°C	vacuum 0.1 kPa	6.7	99.8	Prihatiningtyas et al., 2020a
Lignin-based TFC membrane	3.5 g.L^{-1}	45°C	400–667 Pa	18.5	99.95	Chen et at., 2021
SMA-g-PVA/FS/PVDF composite membrane	-	-	vacuum 100 Pa	44.5 ± 1.5	99.93	Zhao et al., 2021
PA-TFC membrane	1.5 mg.L^{-1} As (V)	60°C	vacuum	16.1	99.9	Xuan et al, 2021
	30 g.L^{-1}	60°C	vacuum	13	99.3	

Li et al.[10] used a dip coating approach to create composite pervaporation membranes from a PVA layer on polyvinylidene fluoride (PVDF) supporting hollow-fiber porous substrate. The PVA layers were crosslinked by glutaraldehyde to stabilize the selective layer in a water environment at a medium temperature. Desalinating tests showed that the membrane's coating layer thickness had been affected by the dip-coating conditions. The membrane had a thick layer of 0.8 μm and could maintain for 300 hours with excellent, consistent performance.

A new kind of PV membrane for desalination was created by Rui Zhang et al.[11]. PVA stabilized with SSA on a surface of a commercial PAN substrate. A facile preparation of dilution, crosslinking, and heating post-treatment made a crosslinked PVA/PAN composite membrane with superior separation performance for desalination. At 70 °C, 100 Pa of vacuum, and 35 g.L^{-1} of NaCl solution, water flux was 27.9 kg.m^{-2}.h^{-1} with a selectivity of 99.8%. A noticeable point is that the SSA functional group increased the composite membrane's thermal resistance.

To improve the wet by cooling water when applying the direct contact mode, Meng et al.[12] prepared the PV membrane carried out by directly contacting mode (DCPV), which consists of three layers, including a PVA crosslinked, a porous PVDF layer and a polytetrafluoroethylene. The desalination results reveal that the DCPV membranes exhibit high productivity and selectivity with good anti-fouling. Zhang et al.[13] fabricated a novel PVA/PAN composite PV membrane via a solution-coating protocol of PVA crosslinked by pyromellitic dianhydride (PMDA) on PAN membranes. The thickness of crosslinked PVA selective layers was 2-μm. The membranes were then tested for salt removal of 35 g.L^{-1} NaCl solution at 70°C. Compared with RO membranes, the produced membranes demonstrated an improved NaCl selectivity of 99.9% and equivalent water flux of 32.2 kg.m^{-2}.h^{-1}.

Chen et al.[14] used a conventional solution-casting approach to make TFC membranes based on lignin. The impact of lignin, a polymeric substance derived from biomass, on desalination performance was investigated. The performance of the prepared membrane possessing a thickness of 0.47 μm bound by 10 wt.% PVA achieved a water flux of 18.5 kg.m-2.h^{-1} and a selectivity of about 99.95 % tested with a 3.5 g.L^{-1} salt feed as feed at 45°C.

Furthermore, using NaClO to treat organic pollutants sticking to membranes impacts the lifespan of membranes. Zhao and co-workers[15] investigated the chlorine resistance of PVA membranes in which active 1,2-diol groups on PVA chains were eliminated by a reaction with $NaIO_4$, grafted-PVA, and styrene-co-maleic anhydride grafted-PVA using fluorocarbon (FS) surfactant to minimize crystallinity and crosslinking. Among PV and RO membranes, the fabricated PV membranes exhibited the highest chlorine resistance (768 g.L^{-1}, NaClO solution). The performance was approximately 45 kg.m^{-2}.h^{-1} permeating flux and 99.93 % selectivity.

Polyamide (PA) materials were once intensively utilized in developing PV membranes to separate organic mixtures[16]. Xuan et al.[17] used interfacial polymerization to prepare a polyamide-based thin-film composite (PA-TFC) membrane for pervaporation salt and Arsenic removals. The PA selective layers were developed via the amidation reaction between diamine monomers and TMC on the PSF substrate. Various diamine structures affecting the separating efficiency of prepared membranes were examined. It is confirmed that the physicochemical characterisitics of the membranes were influenced by the chemical structure of diamines. This led to a change in the water flux of the prepared membrane. For separating 1.5 mg.L^{-1} As(V) at 60 ^{o}C, the PIP-TMC membranes showed an acceptable penetration flux (16.1 kg.m^{-2}.h^{-1}) and about 99.9% selectivity, whereas the penetration flux and selectivity are 13 kg.m^{-2}.h^{-1} and 99.3%, respectively for 30 g.L^{-1} NaCl pervaporation.

Inorganic membrane

Inorganic membranes are more advantageous, such as strong thermal and chemical stability and high foulant resistance[18,19]. Previously, zeolite and amorphous silica-derived membranes have been extensively applied in PV desalinating[20]. Ceramics' greater molecule size and shape capabilities result from their rigid structure and defined pore size, which provides superior separation performance.

Yang and a co-worker developed hybrid carbon-silica-based tubular membranes with no interlayer for PV desalination. The PV membranes were obtained by coating a hybrid silica layer on microporous Al_2O_3 tubular substrates (average pore size of 100 nm) (Ceramic Oxide Fabricates, Australia). A complicated fabrication process was employed with dip-coating, pre-treating, sol-gel reacting, and calcinating procedures at high temperatures in N_2 or vacuum conditions for 4 hours. Three-times replicating synthesis process successfully generated hybrid silica membranes. The results revealed that testing with 1 g.L^{-1} NaCl solution at 60°C, the vacuum calcined (CS-Vc) hybrid carbon-silica based membranes exhibit a permeation flux of 26.5 kg.m^{-2}.h^{-1} and 99.5% selectivity[21]. The authors use a sol-gel method to synthesize a La/Y-organosilica membrane. For 3.5 g.L^{-1} solution of NaCl at 25^{o}C, the prepared membrane synthesized by $La_{25}Y_{75}$-SiO_2 (La:Y = 25:75, mol percent) exhibits a good permeation flux (10.3 kg.m^{-2}.h^{-1}) and excellent selectivity (nearly 100%)[22].

Graphene and its categories, such as graphene oxide, have emerged as alternative materials for the preparation and modification of membranes based on their nano-order structure[23]. Chang et al.[24] created layered graphene-based membranes with a high ion rejection rate and a high water flux. In water separation, graphene oxide (GO) particularly has the most suitable properties[25]. Qian et al. improved the desalinating efficiency of the GO/ PDA based Al_2O_3 membrane through modifying the interlayer spacing in GO structure[26]. Nigiz et al. created a sodium alginate-GO nanocomposite membrane by incorporating commercial GO into the alginate (NaAlg) matrix. The membrane was formed by casting a GO/NaAlg homogeneous solution on a PMMA plate, followed by an evaporation process. The correlation between the GO and NaAlg contents and the separation efficiency of the derived membranes was evaluated. The results indicated that the PV membrane created with 2 wt.% GO and 4 wt.% NaAlg solutions showed an excellent selectivity (99.41 %), but a less permeation flux (8.11 kg.m^{-2}.h^{-1}) at 60°C[27].

In recent years, studies of purification membranes based on MXenes, a new category of metal carbide with a transition of 2D in water treatment and desalination, have attracted great attention because they own a large surface area, good conductivity, biocompatibility, and hydrophilicity[28]. Previous studies revealed that F, C, Ti, O, and H elements are involved in forming Mxene nanosheets with numerous OH and -C=O groups in the chemical structure. As a result, functional groups contribute to the size of interlayer spaces between Mxene laminates, creating a form of transport channel with various molecular sizes. Using a simple filtration approach, Liu et al.[29] developed ultra-thin 2D MXene membranes for pervaporation desalination. Synthesis of Ti_3AlC_2 powders, exfoliation of Ti_3AlC_2 powders, delamination of $Ti_3C_2T_x$, and preparation of MXene composite membrane are all steps in the Mxene manufacturing process. To support the MXene nanosheets, polyacrylonitrile (PAN) microporous support having pore sizes of a few tens of nanometers was utilized. MXenes suspension was added into 100 mL water and sonicated for a few minutes before vacuum filtration through the PAN substrate to form MXene membranes. The prepared membrane possessing an ultrathin thickness of 60 nm exhibits an unexpected permeation flux (85.4 L.m^{-2}.h $^{-1}$) and good selectivity (99.5%) as separating NaCl solution of 3.5 g.L^{-1} at 65°C.

Mixed matrix membranes

There are many advantages to using polymer to produce membranes, due to its low cost, good mechanical properties, high productivity, flexibility, and simple manufacture, while inorganic membranes are generallyc highly selective and thermal and chemically stable. These membranes have a sacrifice between permeate flux and species rejection and have poorer chemical stability and fouling problems, whereas inorganic membranes have complicated manufacturing and high costs. MMs (mixed matrix membranes)[27,28] are hybrid membranes that combine the excellent physicochemical properties of both inorganic and organic materials to develop membranes. The MMMs were formed by a blend, in which inorganic fillers were introduced into a polymeric matrix to improve membrane stability regarding chemical, mechanical, and thermal properties. Innovative inorganic materials are frequently embedded in a polymeric matrix to create MMS materials. The interaction of nanofillers and polymer matrix is crucial to a success of a hybrid-membrane. Currently, nano-fillers incorporated in MMMs applied in pervaporation include zeolite[30], silica[31], carbon nanotubes (CNTs)[32], metal-organic frameworks (MOFs)[33], and graphene[34].

In recent years, silica (SiO_2) has been among the most popular and promising fillers. Incorporating silica into PVA matrix increases the roughness, and free volume in the polymeric membrane, while decreasing the hydrophobic property and thereby improving the pervaporating-desalination performance of the membrane, reported by Chaudhri et al.[35]. The SiO_2/PVA-based composite membranes were synthesized through a dip-coating procedure with carefully controlled penetration, followed by evaporating coating solution to generate a good quality membrane[35]. The PVA-SiO_2 selective layer having a 220 nm thickness reveals a good permeate flux of 20.6 kg.m^{-2}.h^{-1} and 10.4 kg.m^{-2}.h^{-1} with excellent selectivity of 99.9 %, when separating 2 g.L^{-1} and 30 g.L^{-1} salt solutions at a temperature of 70^{o}C, respectively.

Furthermore, Danielli et al.[36] have recently created a unique green membrane originating from a silica/PVA blend. Silica derived from rice husk (RH) material was employed to elevate the separation efficiency of resulting membranes for rejecting salt. The silica/PVA was homogenized via ultrasonic condition followed by crosslinked with dimethylurea (DMU) before casting on a supporting substrate. The resulting membranes obtain the highest water flux of 12.3 $kg.m^{-2}.h^{-1}$ and selectivity higher than 99.9% for 10% silica loading when separating 3.5 wt.% salt mixture at 60°C. Huang et al.[37] introduced graphene oxide nano-fillers into the polyimide (PI) layer via a wet-phase inversion approach to producing nanohybrid nanocomposite membranes applied in seawater desalination. The membranes showed a comparable water flux (about 36.1 $kg.m^{-2}.h^{-1}$) and a superior selectivity at 90°C (99.9 %) compared to the RO membrane.

Metal-organic frameworks (MOFs) are another common filling inorganic material used in MMMs. Liang et al.[38] prepared a blend, including a 53(Al) mixture and a crosslinked PVA solution, to form MMMs via dip-coating procedure with a PVDF hollow fiber support. The MMMs exhibited a high selectivity of approximately 99.9% and a water flux of 19 $kg.m^{-2}.h^{-1}$. The MMMs showed good fouling resistance and long-term stable operation.

Biopolymer-based membranes are a viable alternative to synthetic polymer membranes, which is a current trend in the area, resulting in the appearance of constructing ecologically friendly membranes. MMMs fabricated with biopolymers and inorganic materials, including zeolites, molecular sieves, nanotubes, and graphene oxide, show increases in mechanical properties due to the mobility-prevention of polymer chains. As a result, resulting membranes are more stable and less swell as operation over a long time, especially in separating polar species[5].

Nanocomposite membranes made from cellulose triacetate and cellulose nanocrystals (CTA/CNCs) for pervaporation desalination were developed. CNCs were utilized because many hydroxyls, sulfonic acid, and carboxylic sites were formed on these membranes, improving the hydrophilicity of the resulting membrane. In addition, Indiah et al.[39] investigated the variation of pervaporation performance of a CTA/CNCs-based membrane related to alkaline content in a treatment process. The impact of variables such as Al_2O_3 content, feed temperature, and feed concentration on CTA/Al_2O_3 performance was studied. Compared with a pristine CTA membrane, the CTA/Al_2O_3 membrane formed by 2% CTA exhibits an improved permeation flux higher than 200% and the selectivity around 99.8% as tested with a feed of 30 $g.L^{-1}$ NaCl at a temperature of 70^oC.

CONCLUSION

PV has been considered an emerging membrane process for desalination because it has a comparable permeation flux, excellent rejection, and energy savings compared to RO membranes. The mechanism of the pervaporating process for desalination follows the solution-diffusion theory, in which molecular water is preferentially absorbed on a membrane surface and diffuses through a selective layer while salt molecules are retained. The PV membranes have a crucial role in the PV process. Therefore, numerous studies focus on improving the physicochemical properties of membranes by using different inorganic and organic materials and combining inorganic and organic nanocomposites. Despite their lower thermal and chemical properties than ceramic membranes, polymer membranes are being studied extensively due to their easy preparation method, low cost, and good salt separation performance. The research on mixed matrix membranes has gained considerable attention since the unique properties of inorganic fillers, and polymer matrix can be combined to provide resulting membranes with improved salt separation capabilities and stability at higher temperatures. Many studies have been performed on the lab and pilot scales to develop the future PV process for commercialization on an industrial scale.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHORS' CONTRIBUTION

Minh-Xuan Pham, Mai Thanh Phong and Le-Hai Tran conceived the study. Minh-Xuan Pham wrote the original draft. Le-Hai Tran and Huynh Ky Phuong Ha collated the data. Mai Thanh Phong and Le-Hai Tran wrote and reviewed the manuscript.

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Bài tổng quan

Tổng quan về màng thẩm thấu bốc hơi ứng dụng khử muối

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TÓM TẮT

Hiện nay, việc gia tăng dân số toàn cầu và đô thị hóa đã dẫn đến nguồn nước bị ô nhiễm và làm hiện tượng khan hiếm nước trở thành một trong những vấn đề khó khăn và thách thức. Khử muối là một giải pháp hữu ích để ứng phó với tình trạng khan hiếm nước này. Ngày nay, thẩm thấu ngược là công nghệ khử muối phổ biến nhất, tuy nhiên nó đòi hỏi năng lượng lớn hơn áp suất thẩm thấu trên 500psi để đẩy được dòng nguyên liệu qua màng. Các yêu cầu về năng lượng như đã đề cập trong quá trình khử muối của nước biển hiện đang là thách thức và cần có các biện pháp giúp giảm thiểu năng lượng trong quá trình khử muối. Trong thời gian gần đây, thẩm thấu bốc hơi (PV) đã được quan tâm nghiên cứu với vai trò là một giải pháp màng lọc giúp khử muối trong nước biển với nhiều lợi ích như: khả năng loại bỏ muối cao, tiết kiệm năng lượng và giảm thiểu nguy cơ tắc nghẽn màng. Như vậy, áp dụng quá trình/ phương pháp thẩm thấu bốc hơi PV có thể được coi là một công nghệ ``xanh''. Trên cơ sở đó, nghiên cứu này đặt ra mục tiêu là cung cấp một cái nhìn tổng quan về việc sử dụng quá trình/ phương pháp PV trong khử muối, cụ thể là tập trung vào các vật liệu màng và một số ý tưởng được sử dụng trong PV. Nhìn chung, quá trình khử muối bằng hơi nước dựa trên cơ chế khuếch tán dung dịch, trong đó động lực của quá trình phân tách về cơ bản là sự khác biệt về áp suất hơi riêng phần giữa các mặt cấp và thấm được phân chia bởi màng chọn lọc PV. Các màng polymer đang được nghiên cứu rộng rãi do phương pháp điều chế dễ dàng, chi phí thấp và hiệu quả tách muối tốt so với màng hữu cơ. Cho đến nay, xu hướng nghiên cứu về màng ma trận hỗn hợp đã thu hút được sự chú ý đáng kể. Bởi vì sự kết hợp những tính chất độc đáo của các chất độn vô cơ và ma trận polyme tạo ra màng với hiệu quả tách muối được cải thiện và ổn định ở nhiệt độ cao hơn. Thẩm thấu bốc hơi đã cho thấy triển vọng cao cho quá trình khử muối với năng suất tốt và tính chọn lọc cao. Theo đó, nhiều nghiên cứu đã được thực hiện ở quy mô phòng thí nghiệm và pilot để phát triển quy trình PV trong tương lai, hướng tới thương mại hóa ở quy mô công nghiệp.

Từ khoá: Thẩm thấu bốc hơi, màng lọc, màng mỏng phức hợp, lọc, khử muối

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