WETTING PHENOMENA IN MEMBRANE DISTILLATION FOR SEAWATER DESALINATION

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Contents

Summary

Seawater desalination is a feasible option for diversifying a water-supply portfolio. Membrane-based technologies have been made particularly attractive by cost-effective and efficient subsurface feedwater supply processes and water treatment technologies developed to satisfy the globally increasing demand for water. Membrane distillation (MD) has emerged as a sustainable desalination technology when it utilizes low-grade waste heat, but membrane wetting is one of the main obstacles to its widespread industrial application. This chapter presents a broad review of wetting in the MD desalination process. Wetting characteristics and mechanisms, and detection methods are explained. Further, complex physical and chemical interactions between feed and membrane material during operation are highlighted. The dynamics of wetting and the effects of operational parameters are described in detail. The chapter concludes with two practical strategies for wetting control — membrane design and in-process approaches that are contrasted and an outlook on future developments.

1. Introduction

Desalination technology operates in three ways that involve pressure, electricity, or heat. Pressure desalination, or reverse osmosis (RO), is an important, energy-efficient desalination technology where pressurized seawater flows through a semi-permeable membrane to separate dissolved ions from seawater. In electrical desalination, an electric current de=ionizes the seawater. Finally, the oldest desalination technology is thermal desalination, where the water is purified by the phase change from liquid to vapor (Gilron, 2016). This requires more energy than pressure-based desalination and is, therefore, more costly.

Membrane distillation (MD) has emerged as a promising thermal desalination technology that uses a membrane contactor (Sirkar et al., 2017). The membrane separation process is thermally induced and has been known for more than six decades.

MD can be used as a brine-concentration technology when RO is not applicable due to an excessive osmotic pressure difference between the two sides of the membrane (Sanmartino et al., 2016). Some properties of MD make it a competitive technology in specific applications, including treatment of brine (TDS >70,000 ppm), removal of volatile organic compounds, water purification in the pharmaceutical, chemical, and textile industries, and food and beverages concentration (Alkhudhiri and Hilal, 2018).

Although MD is an attractive technology for desalination, it has some drawbacks. Central goals of research into MD desalination are increasing energy efficiency and reducing fouling and membrane wetting. Particularly in MD commercialization and research – but also in other MD application areas – membrane wetting is a crucial topic because it is related to the technology's long-term stability (Thomas et al., 2017).

Membrane wetting occurs when the feed solution penetrates the pores of hydrophobic membrane and affects permeate quality, flux, and process efficiency. Addressing this problem requires an accurate definition of membrane wetting and studies that characterize it and identify its causes (Rezaei et al., 2018).

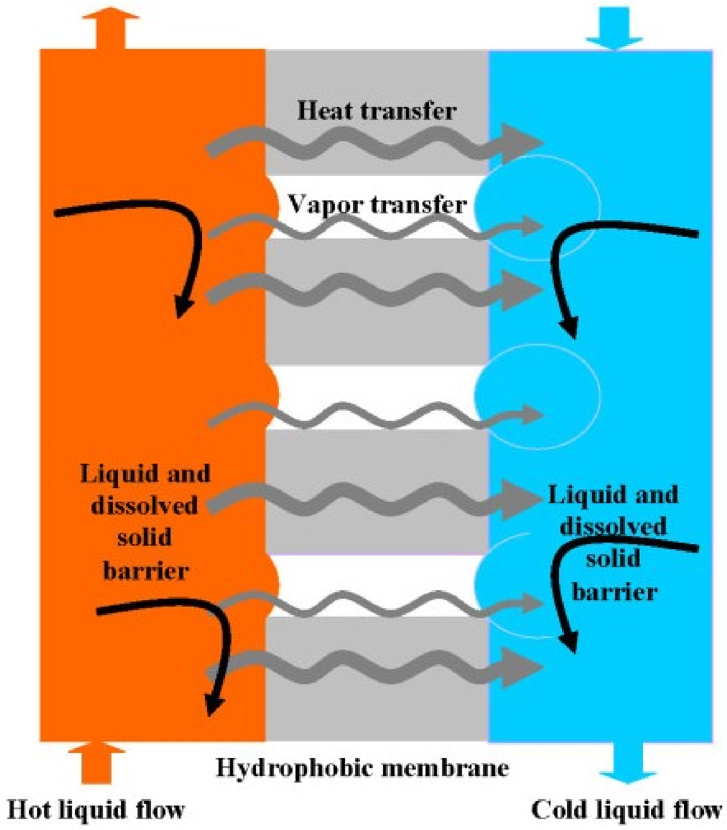

Figure 1. Principle of membrane distillation

MD water desalination is considered a low-temperature operation, alternative to conventional separation technologies such as distillation for high-purity water production. It is a thermally driven process in which water-vapor pressure induced by the temperature difference across the porous hydrophobic membrane acts as the water vapor transport force (Figure 1). The membranes in MD should allow passage of vapors only and retain non-volatile substances. Theoretically, the permeate quality is close to 100% free from salts (Mohamed Khayet, 2011). MD membranes are produced from hydrophobic polymers, such as polytetrafluoroethylene (PTFE), polyvinylidene fluoride (PVDF), and polypropylene (PP), by facile phase separation, stretching and electrospinning of flat sheets, and extrusion of hollow fiber membranes to ensure their optimal performance. Interestingly, heat energy, such as solar energy, geothermal energy, and low-grade waste-heat energy, can be used in the MD process (Bourouni and Chaibi, 2005).

1.1. Principles and Configurations of MD

In MD, mass is transferred through a porous hydrophobic membrane. (Curcio and Drioli, 2005). To achieve a vapor-pressure gradient, several module configurations, such as direct-contact membrane distillation (DCMD), air-gap membrane distillation (AGMD), sweeping-gas membrane distillation (SGMD), and vacuum membrane distillation (VMD), are used (Figure 2). Various MD configurations have been evaluated extensively for desalination of seawater (Alkhudhiri et al., 2012; A. K. An et al., 2017; Bonyadi and Chung, 2007; Ying Chen et al., 2017; Dong et al., 2015; Munirasu et al., 2017). On the lab scale, these configurations have shown high salt rejection (99%) and water fluxes (10 – 48 L•m-2•h-1) (Alkhudhiri et al., 2012; A. K. An et al., 2017; Bonyadi and Chung, 2007; Ying Chen et al., 2017; Dong et al., 2015; Munirasu et al., 2017; Nthunya, Gutierrez, Verliefde, et al., 2019; Nthunya, Gutierrez, Lapeire, et al., 2019). They have also been investigated to purify water sources contaminated with heavy metals and pharmaceutical and textile wastewaters (Criscuoli et al., 2008; ZW Ding et al., 2011; Zolotarev et al., 1994), and high separation efficiencies have been achieved.

In DCMD, the hot solution (feed) and cold water directly contact the membrane surfaces. Water vapor is transferred from the hot feed side to the cold permeate side, where it condenses. The vapor gradient across the membrane transfers the water vapor due to the vapor pressure difference (Tomaszewska, 2000). Unlike otherwise stated, DCMD is hereafter considered the default MD configuration. Although this configuration is known to be susceptible to heat loss, Lee et al. (2011) achieved a thermal efficiency of 0.73-0.87 by using a countercurrent cascade, thus significantly improving MD. In AGMD configuration, only the hot feed is in direct contact with one membrane surface. The total length of vapor diffusion is the sum of membrane thickness and air gap distance. Stagnant air is introduced between the membrane's hot surface and the condensation side. Water vapor passes through the air gap to the membrane's condensation compartment (Alsaadi et al., 2013). This configuration has been applied in several contexts, for instance, to remove toxic metals from water by using an alumina-modified electro-spun PVDF nanofiber membrane with a contact angle close to 150° (Bajáková et al., 2011; Zolotarev et al., 1994).

In SGMD configuration, an inert gas is used to sweep the vapor from the membrane's permeate compartment to the condensation compartment outside the membrane area. A mobile gas barrier prevents heat loss and facilitates mass transfer (M. Khayet et al., 2003). Onsekizoglu (2012) has summarized the principles and limitations of and advances in SGMD membrane configurations, including process fundamentals, membrane characteristics, membrane materials, membrane modules, process parameters, flux enhancement, and transport mechanisms, and polarization phenomena.

In VMD configuration, a vacuum is created on the permeate side of the membrane. The water vapor is driven out of the membrane and condensed. In this configuration, heat loss is significantly minimized (Boukhriss et al., 2014). VMD has also been used in solar-energy-driven systems to recover water from polluted solutions (Khaled et al., 2017; J. Mericq et al., 2011).

Notably, in all configurations, the heated (feed or retentate) solution is in direct contact with the hydrophobic membrane. The hydrophobicity of the membrane allows water transfer in the vapor phase, while only the liquid phase of the water and non-volatile compounds is retained. For this reason, the volatile compounds are converted to the vapor state; then they diffuse through the membrane pores and are ultimately condensed and collected on the permeate/distillate side. The first MD patent was granted to Bodell in 1963, and the results achieved were first published in 1967.

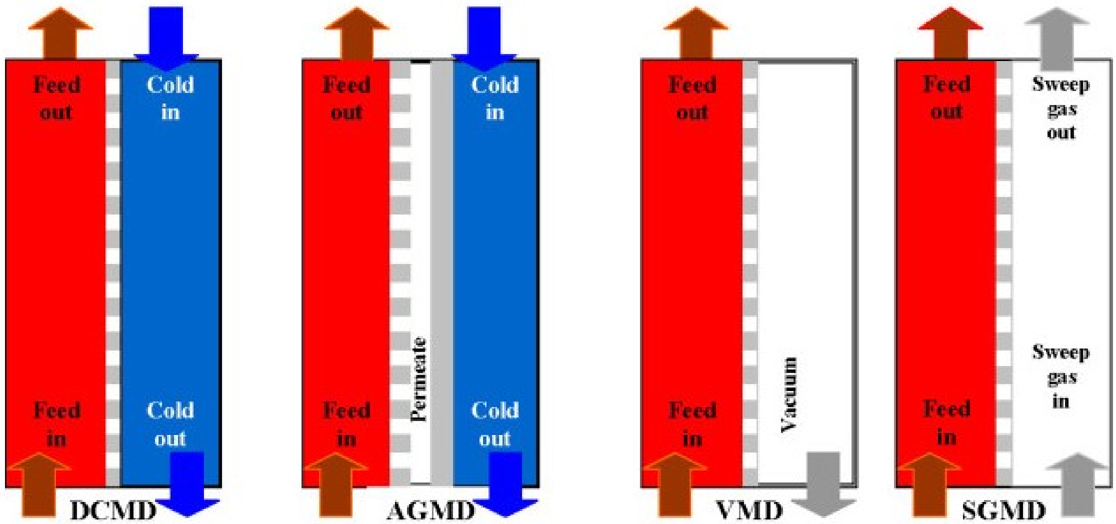

Figure 2. Schematic representation of the four different configurations commonly used in MD.

1.2. Challenges in Membrane Distillation for Seawater Desalination

Although MD is envisaged as a technology with great potential for seawater desalination, its performance is severely affected by two key factors: (i) wettability as a result of condensation of water vapor inside the pores of the membranes and (ii) fouling due to the accumulation of biofilm and organic, inorganic, and colloidal substances on the surface or in the internal pore structure of the membranes (Camacho et al., 2013). As previously stated, hydrophobic MD membranes should be used to prevent membrane wetting, but these are susceptible to fouling. Composite polymeric membranes with a hydrophilic support layer exhibit increased wettability, which affects water vapor diffusion through the membrane and compromises rejection efficiency (Manjula and Subramanian, 2006). As a result, numerous membrane modification studies have been conducted to overcome the fouling and wettability challenges associated with MD membranes (Lim et al., 2009; Tijing et al., 2015). Although MD is a promising technology that has been widely tested on the laboratory scale, its industrial implementation has progressed at a slow pace.

2. Wetting Phenomena in Membrane Distillation

Membrane wetting involves complex physical and chemical interactions between feed and membrane material during operation (Alklaibi and Lior, 2005). Ideally, the non-wetting liquid forms an interface at the membrane pores due to the hydrophobicity of the membrane. As a result of capillary action and high surface tension, the liquid feed forms a convex meniscus that impedes penetration of liquid into the membrane pore. Therefore, the liquid feed in contact with the membrane bulges into the pore until the capillary pressure arising from the curved interface's surface tension balances the pressure drop caused by the partial pressures of vapors and air across the membrane. When this pressure balance is disturbed, membrane wetting occurs, and the membrane starts to lose its hydrophobicity and allows water bridging across the membrane thickness (Rezaei et al., 2018).

The fundamental cause of membrane wetting is a change in the conditions that result in the operating pressure exceeding the liquid entry pressure (LEP). The membrane resistance to pressure can be reduced by chemical and mechanical degradation, which typically occurs in long-term operation.

Membrane fouling is the primary cause of a decrease in LEP, which results in wetting. The LEP is defined theoretically as the minimum transmembrane pressure required for the feed solution to penetrate the largest pores. Fouling refers to the deposition of material on the membrane surface and in membrane pores (Camacho et al., 2013; Gryta, 2007; Hausmann et al., 2011; Tijing et al., 2015). Other causes of wetting include the presence of surfactants, which reduce the surface tension of the feed, capillary condensation, and membrane damage (Ge et al., 2014; J. G. Lee et al., 2018). A build-up of foulant may reduce the LEP by enlarging the pore mouth, damaging the membrane (Elena Guillen-Burrieza et al., 2013), and clogging the pores (Kharraz et al., 2015).

2.1. Mechanism of Wetting

Wetting in MD refers to liquid water permeation through membrane pores from the feed side to the permeate side. Membrane wetting decreases permeate quality by enabling the diffusion of salts or convective flow of feed to the permeate side. It is often less obvious in short-term experiments but has become the main issue in long-term MD operations (Marek Gryta, 2005a). Wettability of the MD membrane can be considered locally (from the pore perspective) and spatially (from the area perspective):

We can distinguish at least four stages of membrane wetting, as shown schematically in Figure 3. Initially, a membrane is (i) non-wetted. As time passes, (ii) the surface of a membrane becomes wetted in more and more places, and the feed floods the pores on the membrane surface (surface wetting); (iii) the pores in the wall are then wetted, and some of the wetted pores form channels connecting distillate with feed (partially wetted). Eventually, (iv) most of the pores undergo wetting, and the MD process stops due to full wetting. The stages of membrane wetting as presented in Figure 3 are determined based on the changes occurring in the membrane or by appropriately interpreting the data continuously collected during the MD process, for instance, on permeate flux and distillate electrical conductivity.

Alternatively, the membrane can be viewed as having a heterogeneous degree of wetting: (a) A non-wetted membrane means no pore-wetting and thus maximum vapor transport, the highest flux, and complete salt rejection. A prolonged operation may result in (b) a surface-wetted membrane, where the gap for vapor transport is reduced, but feed water does not reach the permeate side. Surface wetting shifts the liquid/vapor interface inside the membrane pore and leads to a slight decrease in permeate flux due to temperature polarization, which lowers the temperature of the pore's evaporating interface (Gryta, 2016).

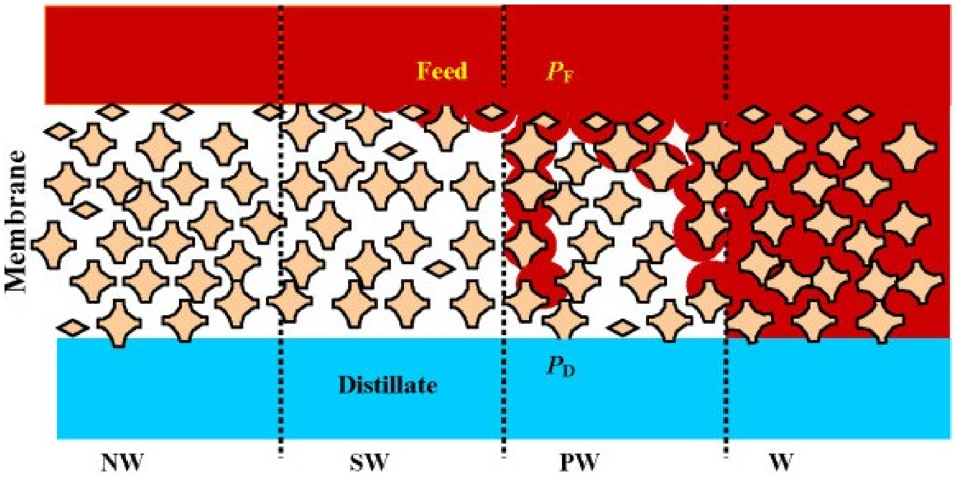

Figure 3. The stages of membrane wetting during the MD process. NW: non-wetted; SW: surface-wetted; PW: partially wetted; and W: wetted. P_F and P_D: hydraulic pressure on the feed and distillate sides, respectively

Scaling due to super-saturation of the solute formed by solvent evaporation may occur inside the pores in the vicinity of the meniscus (Gryta, 2016). Further, crystal growth inside the pores accelerates scaling because it inhibits diffusive transport of solutes and solvent between wetted pores and the feed bulk, raising solute concentrations locally. When membrane pore size is widely distributed, (c) some of the pores can be thoroughly wet, which allows the feed water to permeate through them, while the vapor-transport gap decreases in other pores. In this case, the MD process can be continued if most pores are dry. However, partial wetting can either decrease the permeate flux due to a reduction in active surface area for mass transport (Karakulski and Gryta, 2005) or increase it due to wetting of some pores (i.e., vapor transport is overtaken by liquid transport) but result in low solute rejection (Noel Dow et al., 2017).

Interestingly, all hydrophobic membranes used in MD, such as PP, PTFE, and PVDF, have shown partial wettability in long-term use (Gryta, 2015). Any MD system treating feed water without volatile components shows less than 100% rejection when experiencing partial wetting. Lastly, (d) full wetting of all pores in the membrane occurs when all membrane pores allow permeation of feed water, which significantly deteriorates permeate quality due to the penetration of contaminants. The membrane no longer acts as a barrier, which results in a convective flow of liquid water through the membrane pores, rendering the MD process ineffective (Rezaei et al., 2017). Note that, in an equipressure system (i.e., without trans-membrane pressure between the feed and the permeate side), low-rate salt transport via diffusion occurs. Significant loss of rejection is expected from the convective flow of the feed solution to the permeate side driven by pressure. Several mechanisms have been proposed to explain the occurrence of membrane wetting based on feed properties, operational conditions, system design, and membrane materials.

2.2. Wetting Characteristics

The easiest way to detect membrane wetting is by evaluating permeate quality, more specifically, conductivity. Theoretically, wetting-free MD results in complete salt rejection. When the membrane is wet, the solute can diffuse through the liquid along the membrane pore from the feed to the permeate side, which leads to an increase in permeate conductivity. This simple detection method is only valid when the feed does not contain any volatile component (e.g., ammonia or carbon dioxide), as this may also increase permeate conductivity (Warsinger, Servi, et al., 2017). In this case, more sophisticated methods are required to detect membrane wetting. Wetting can also be identified visually by a change in membrane opacity from opaque (dry membrane) to transparent (wet membrane) (Noel Dow et al., 2017; Jacob et al., 2019). Alternatively, wetting can be detected by a change in transmembrane pressure or by membrane autopsy.

As discussed earlier, the LEP is an accurate measure of wetting, and its value can be used as a direct method for predicting the likelihood of membrane wetting. Theoretically, the membrane should have an LEP > 0 to avoid instant wetting, but – in practice – it should be greater than the pressure applied for MD operation. The LEP is affected by the interfacial tension of the feed, the membrane contact angle, the membrane surface structure, and pore size (Rezaei and Samhaber, 2016). The LEP can be measured by two approaches: statically via bubble point (Smolders and Franken, 1989) or dynamically via the MD test. However, the latter has been abandoned because membrane compaction during the test affects measurement (Durham and Nguyen, 1994). A simple method for membrane characterization is measuring the contact angle between feed droplet and membrane surface (Eykens et al., 2017), which gives the relative wettability of a membrane by the liquid tested. If the contact angle of the feed water solution is < 90°, instant wetting is expected. However, immediate non-wettability is seen as less relevant in predicting wetting during MD operation. The (static) contact angle between liquid droplet and membrane surface is measured by a goniometer as the angle between flat membrane surface and a line tangent to the drop's curved face at the point of three-phase contact (Onsekizoglu, 2012). The advancing water-contact angle is associated with membrane hydrophobicity, and the receding angle is related to the degree of molecular reorientation necessary to create a new equilibrium with the aqueous solution (Mohamed Khayet and Matsuura, 2004). The contact angle is easy to measure, but it can show hysteresis and is influenced by the membrane's surface structure (roughness) (Adamson and Gast, 1997). Information on membrane properties (bubble point) combined with the contact angle allows the liquid entry pressure to be estimated; thus, no compounding effect of compaction affects the results. This method has been widely used in MD membrane development to evaluate wettability.

Less popular methods for membrane-wetting analysis involve penetrating drop concentration, sticking bubble, and temperature penetration. A comprehensive overview can be found elsewhere (Rezaei et al., 2018).

2.3. Methods of Wetting Detection

Feed solution can be contaminated with compounds that reduce surface tension (e.g., surfactants) and cause water penetration into the membrane pores. In such cases, wetting can be reduced by using a modified membrane. However, it cannot be universally non-wettable; So, the membrane must be modified according to the feed water properties. Two fast and straightforward pre-selection methods are the drop test and the buoyancy test (see Figure 4). In the former, the shape of the feed droplet on the membrane surface is observed. A membrane on which the droplet spreads or infiltrated by the droplet is not suitable for MD of the feed water. In the latter method, a piece of membrane is placed on the feed surface; if it does not sink, it is suitable for MD of the feed water used in the test (Ahmed et al., 2017).

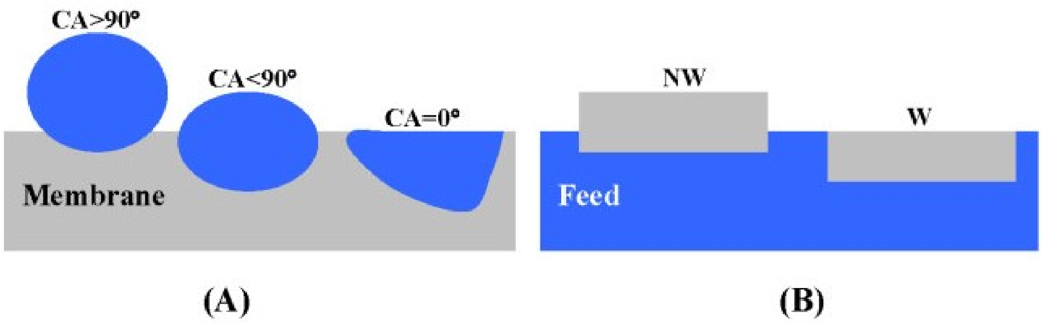

Figure 4. Two approaches to determining a membrane’s resistance to wetting: A) water-drop test and B) buoyancy test. NW: non-wetted; W: wetted

Choosing the best membrane from those that have successfully passed these two tests requires further research, such as contact angle (CA) measurements. Membranes with a CA greater than 90˚ are assumed to be resistant to wetting by the feed water used. However, CA measurements relate only to a membrane’s surface properties, while wetting usually depends on the entire wall cross-section properties. Hence, even if its CA value is slightly lower than 90˚, a membrane may prove suitable for the MD of the feed water it was tested with. For example, polypropylene membranes, which exhibit a CA of 86˚ for de-mineralized water, are not wetted by this feed in continuous MD operation over several months (Marek Gryta, 2005b).

The efficiency of the MD process is determined by the vapor pressure at the feed/pores interface, which depends on feed temperature and concentration. Since polarization phenomena reduce this pressure, ensuring suitable hydrodynamic conditions in the module is vital. This requires a corresponding increase in the feed-flow velocity, which, however, also increases the hydraulic pressure. Consequently, the membrane must exhibit the highest possible LEP, which forces the liquid into the pores. Wetting also depends on pore size; a good LEP value above 0.1 MPa is usually obtained for membranes with a pore diameter below 0.2 μm.

Although these tests help in selecting a suitable membrane, evaluating the resistance to wetting requires MD tests, preferably under conditions similar to those in an industrial installation. Due to scaling, fouling, and degradation of the membrane matrix, membrane pores start to fill with the feed during the MD process, even if a membrane with favorable CA and LEP has been selected. This can be counteracted by choosing an appropriate matrix material and membrane-surface morphology. Assessment of new membranes' effectiveness is complex because the wetting process may proceed very slowly. The majority of MD membranes resistant to wetting do not show significant changes during the first 100-200 hours of operation of the module, so in many cases, MD process tests must run for over 1000 hours (Gryta, 2005). The wetting detection methods depend on the module operating time and the degree of wetting present.

A typical course of changes in permeate flux and conductivity is shown in Figure 5. Initially (membrane in the non-wetted state), the flux is stable, and the distillate obtained has a low conductivity, usually at the level of 2-3 μS/cm. Conductivity remaining constant while the permeate flux increases slightly is an indication of membrane-surface wetting. In this case, the flux increases because the thickness of the gas layer in the wall decreases, which reduces mass transport resistance. By advancing the wetting in the pores, the thickness of the gas layer reduces further, but at the same time, the resistance to heat transport from the feed to the evaporation surface increases, which lowers its temperature. As a result, the permeate flux starts to decrease systematically, but the distillate's purity does not deteriorate, as a gas layer still separates the feed. When distillate conductivity starts to increase gradually during the MD process (Figure 5, from 250 h), the partial-membrane-wetting stage has been reached.

The course shown in Figure 5 applies when the hydraulic pressure values on the feed and the distillate side are similar or when $P_{\mathrm{D}} > P_{\mathrm{F}}$. Otherwise, for $P_{\mathrm{F}} > P_{\mathrm{D}}$, when the partial wetting stage has been reached, feed leakage through the membrane will occur, which causes an increase in the amount of water obtained on the distillate side and a sharp increase in the specific conductivity of the distillate (Chamani et al., 2018).

An essential step in studying membrane wetting is to evaluate the effect of drying. To this end, the MD process is interrupted, and the membranes are thoroughly rinsed with distilled water and then dried (e.g., by blowing warm air through the module). If, after restarting the MD process, permeate flux increases significantly while distillate conductivity decreases (the case presented in Figure 5), the tested membranes were wetted in the MD process.

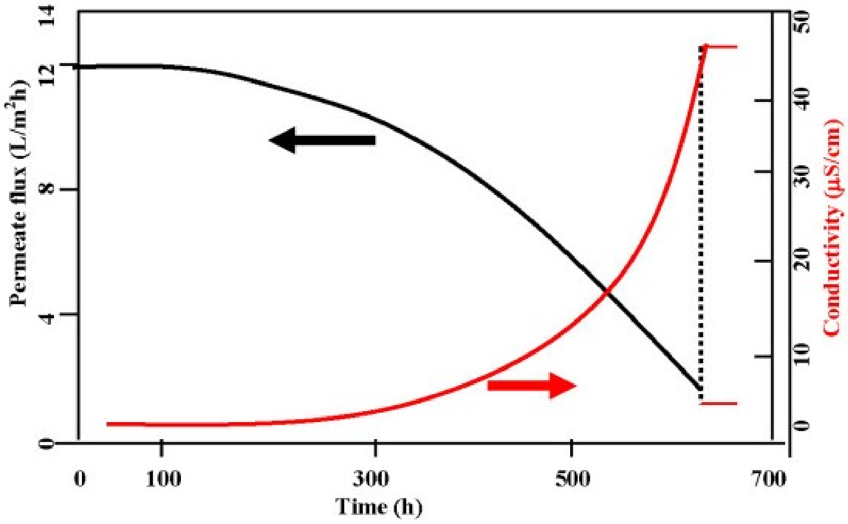

Figure 5. The course of changes in permeate flux and distillate conductivity as a result of progressive membrane wetting. D – membrane drying

Gas flux measurements of the membranes assembled in an MD module can be used to test the degree of surface wetting. In the case of a dry membrane, the gas flux increases linearly with increasing gas pressure. If the pores at the surface of the membrane are wet, they block the gas flow. The gas pressures used in these measurements are usually much lower than the LEP, so the gas cannot force the liquid out of the pores. If the measuring system is supplied with dry gas, the membrane surface dries out, enabling gas flow. As the measurements continue, the water evaporates from the pores consecutively, which increases the gas flow. In this case, the gas flux value obtained depends not only on the gas pressure but also on the degree of surface wetting and the duration of measurements (drying time). For this reason, and while maintaining repeatability of the measurement sequences, it is possible to demonstrate the effect of a particular period of MD module operation on the degree of membrane wetting, as shown in Figure 6.

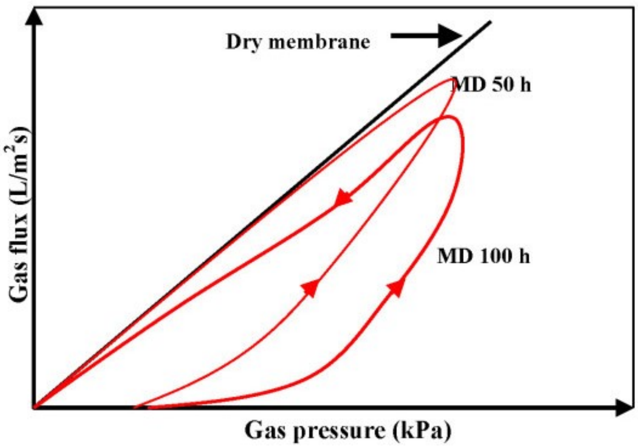

Figure 6. Changes in gas flux indicating differences in the degree of wetting of the membrane surfaces

Other methods are relevant in the laboratory context and include measurement of permeate electroconductivity, transmembrane impedance (Chen et al., 2017), and optical transmittance (Jacob et al., 2019). The laboratory methods are also used to determine changes in the membrane wall but require membrane autopsy. One of the most frequently used techniques is scanning electron microscopy combined with energy-dispersive X-ray spectroscopy (SEM-EDX). Preparation of a membrane sample for SEM testing completely removes water from the pores, but the dissolved salts remain and are deposited in the wetted pores. The SEM-EDX line analysis helps to detect salt components of surface pores and allows them to assess the fragments of the wetted wall during the MD. Some salts, such as NaCl and KCl, tend to crystallize at the edges of the pores. In this case, SEM observation of the dried membranes on the distillate side enables detection of the places where the pores have formed wetted channels through the membrane wall (Figure 7).

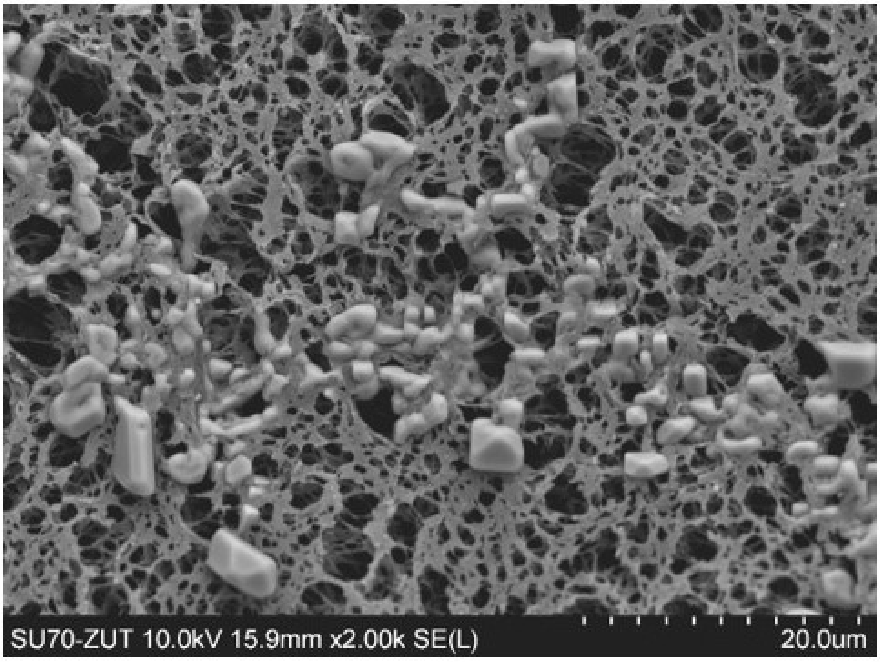

Figure 7. Scanning electron microscope (SEM) images of membrane surface on the distillate side with NaCl crystals (composition confirmed by SEM-EDX analysis)

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Biographical Sketches

Mohammad Rezaei received his bachelor's degree in the inorganic chemical engineering in 2007 and a master's degree in process engineering in 2009 from Azad University in Tehran, Iran. In 2010 he was granted a Marie Curie Actions from the European Commission to research "Multi-Scale Computational Modeling of Chemical and Biological Systems" in Austria and Greece. In 2017, he received his Ph.D. in membrane separation technologies from Johannes Kepler University Linz, Austria. He has published several scientific articles, and several of them are associated with the membrane distillation (MD) process. His research activities encompass fundamental studies of membrane process design and applied studies in wetting control in MD. His teaching duties include Chemical Process Engineering and related lab courses. His recent research project involves seawater membrane desalination, energy efficiency for solar evaporation and thermal desalination, and techno-economic analysis of wastewater treatment in iron and steel industries.

Marek Gryta received his Diploma in chemical engineering in 1988 from Technical University of Szczecin, Poland, and his Ph.D. in 1995 from this University. At present, he is a Full Professor of chemical technology at West Pomeranian University of Technology in Szczecin, Poland. His main research interests are focused on studying membrane processes applied for water desalination and wastewater treatment. He has published a number of scientific articles (over 300) and about 50 patents in this research area. The majority of them are associated with the membrane distillation process. His teaching duties include the lectures concerning Inorganic Chemistry, Chemical and Environmental Analysis, Separation Processes, and Technical Drawing. He has realized several research projects focusing on applying membrane processes for water treatment in the power plants and industry. His recent research project involves utilizing membrane distillation for the separation of brines contaminated by oil and surfactants. The major problem constitutes the durability of hydrophobic membranes (fouling/scaling and wettability), particularly during the treatment of brines containing various surface-active contaminants. In this project, the polypropylene membranes were applied, and their performance will be confirmed by long-term MD studies (over several months).

Muhammad Roil Bilad received his Diploma in Chemical Engineering in 2005 from Institut Teknologi Bandung, Indonesia, and his Ph.D. in 2012 from KU Leuven, Belgium. At present, he is a Senior Lecturer of chemical engineering at Universiti Teknologi Petronas, Malaysia. His main research interests are focused on membrane processes and membrane engineering. He has published a number of scientific articles (over 150) and co-invented 3 patents in this research area. The main focuses of his research are on control of membrane fouling and scaling through module design approaches as well as a novel bioprocess involving membrane filtration. His teaching duties include the lectures on Principles of Chemical

Engineering, Fluids Mechanics for Chemical Engineering, Advanced Reaction Engineering, and Cogeneration and Utility Systems. His recent research projects involve low-pressure filtration systems for various applications, process intensification involving membrane distillation, and biological process.

Alba Ruiz-Aguirre has a degree in Chemical Engineering and obtained her Ph.D. (Extraordinary Ph.D. Prize of University of Almería) in 2017. She is currently in receipt of a Juan de la Cierva postdoctoral contract awarded by the Spanish Ministry of Science, Innovation, and Universities. Her research topics are focused on membrane technologies applied to water treatment, mainly membrane distillation (MD) and diffusion dialysis (DD), and the application of solar energy to the processes. She has worked with several solar MD pilot plants and has been involved in evaluating several commercial MD technologies. She has been involved in 5 national and international R+D projects, has 17 papers in SCI journals, and 49 contributions to different International Conferences.

Hamid Fattahi Juybari is a Research Scholar in the Birck Nanotechnology Center, Department of Mechanical Engineering of Purdue University, USA, and is a Ph.D. Candidate in the School of Materials and Advanced Processes Engineering of Amirkabir University of Technology, Tehran, Iran. He received his bachelor's degree in Textile Engineering in 2012 from the University of Guilan and a master's degree in Nano-fibrous Structure Engineering in 2014 from Amirkabir University of Technology. His research focuses on engineering material and developing membranes that address challenges at the intersection of water and energy, and he is broadly interested in applications related to desalination and advanced water treatment.

Jianhua Zhang received his bachelor's degree in Chemical Engineering in 1996 at Xi’an Jiaotong University, China. He was awarded a Ph.D. degree in 2011 from Victoria University, Australia. He worked in the chemical industry for 10 years before he continued his Ph.D. study at Victoria University in 2008. He has been working at Victoria University as a Senior Research Fellow in the water treatment area since 2011. His research covers different technologies for potable reuse, wastewater treatment, and desalination, including filtration, biological activated carbon, membrane distillation, reverse osmosis, and advanced oxidation.

Lebea N. Nthunya received his Bachelor’s Degree in Chemical Technology in 2013 from the National University of Lesotho. In 2016, he graduated his Master’s Degree (Distinction) from the University of Johannesburg. Finally, Lebea Nthunya is a dual Ph.D. graduate between Ghent University (Belgium) and University of South Africa. His key research interest is based on developing state-of-the-art water purification systems comprising polymeric nanofibre adsorbents and the filtration membranes. Remarkably, he has published several papers based on Membrane Distillation. Also, Nthunya has worked on several water quality assessment projects in the Limpopo and Mpumalanga Provinces of South Africa, as well as Water Quality Assurance in all Lesotho Districts Under the supervision of Water and Sewerage Company (WASCO). Nthunya headed student charter at South African Nanotechnology Initiative (SANi). He is currently working as a Chemical Engineering Lecturer and Researcher at Tshwane University of Technology (South Africa).

Patrick Loulergue received his Ph.D. in Environmental Process Engineering in 2012 at INSA Toulouse (France). He then joined the Université de Rennes 1 (France), first as a Postdoctoral fellow and then as an associate professor since 2014. In July 2018, he was a visiting professor at the Sichuan University (Chengdu, China). His research activity lies at the interface of chemical engineering and material science, focusing on sustainable processes and materials. In particular, his research interests are related to the synthesis, characterization, and use of membranes for filtration and distillation processes in the fields of water treatment and biotechnology.

Mark Hlawitschka received his Diploma in Mechanical and Process Engineering in 2008, and his Ph.D. in the field of liquid-liquid extraction in 2013 from the University of Kaiserslautern. After his habilitation in the field of “multiscale investigations of reactive bubble columns.” At present is leading the institute of Process Engineering at the Johannes Kepler University in Linz. His teaching includes, among others, Mechanical and Thermal Process Engineering, as well as Apparatus Design. His research spreads to the field of thermal process engineering. Among his last topics are the development of sophisticated measurement techniques and Computational Fluid Dynamics simulations for multiphase flows, detailed analysis of single effects, such as coalescence and mass transfer of single particles, as well as equipment design, such as extraction columns and mixer-settlers.