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Desalination by vacuum membrane distillation: The role of cleaning on the permeate conductivity

A. Criscuoli [*], M.C. Carnevale

Institute on Membrane Technology (ITM-CNR), c/o University of Calabria, via P. Bucci cubo 17/C, 87030 Rende, CS, Italy

HIGHLIGHTS

- Assessment of the purity of the permeate obtained by VMD of seawater.
- Analysis and comparison of the effects of a partial and of a total cleaning.
- Pure water or high-purity water obtained as permeate.

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ABSTRACT

In this work, desalination tests were carried out by vacuum membrane distillation, with the aim of investigating the purity (in terms of conductivity) of the produced permeate. Consecutive experiments, with and without cleaning in between, were made on lab-prepared modules equipped with commercial capillary polypropylene membranes. In particular, by working at fixed operating conditions (feed flow rate and composition, temperature and vacuum pressure) the effects of a partial and of a total cleaning procedure on the permeate conductivity were analyzed and compared. Depending on the used approach, pure water or high-purity water can be obtained as permeate.

1. Introduction

The desalination of seawater to produce fresh water is a practice that has been used since long time. Concerning distillation, already in AD 200, sailors were producing onboard fresh water by boiling seawater and collecting the water vapor into large sponges, from which they recovered the sweet water. Today, the most used processes to produce fresh water from seawater are both thermal, like distillation, and membrane operations, like reverse osmosis and electrodialysis. In last years, researches on the application of thermal membrane operations, like membrane distillation, have appeared in the literature, confirming the potentiality of this membrane process to efficiently recover fresh water from salty solutions, also highly concentrated. In membrane distillation, the aqueous feed is in contact with a surface of a microporous hydrophobic membrane and, due to the membrane hydrophobicity, cannot pass as liquid inside pores that remain dry. Therefore, by creating a difference of partial pressures across the membrane, it is possible to transport only water vapor from the feed to the permeate side. Depending on the way this driving force is created, there are four main configurations of the membrane distillation (*Direct Contact Membrane Distillation (DCMD)*: at the permeate side is sent a cold aqueous strip; *Air Gap Membrane Distillation (AGMD)*: at the permeate side there is an air gap through which the water vapor is transferred before being condensed on a cold surface; *Sweep Gas Membrane Distillation (SGMD)*: at the permeate side is sent a sweep gas and the stripped water vapor is condensed outside the membrane module; *Vacuum Membrane Distillation (VMD)*: the permeate side is under vacuum and the water vapor is condensed outside the membrane module). Each configuration presents some advantages and disadvantages. In desalination, the *AGMD* [1–13], the *DCMD* [14–24] and the *VMD* [25–35] configurations have been successfully applied, providing sweet water as permeate. If the membrane is not wetted during the process, the permeate conductivity is usually lower than 50 μS/cm, with a salt rejection of at least 99.90% Therefore, the studies reported in the literature mainly focus on the enhancement of membrane stability in time and on the permeate flux improvement (that is strictly linked to the system productivity). At the author's best knowledge, no investigation was made on how the purity of the distillate can be affected from adopting or not cleaning procedures during the process. This is because the produced water is usually sweet enough to be employed for drinking/agricultural purposes (after re-mineralization up to required values), the

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[*] Corresponding author.
E-mail address: a.criscuoli@itm.cnr.it (A. Criscuoli).

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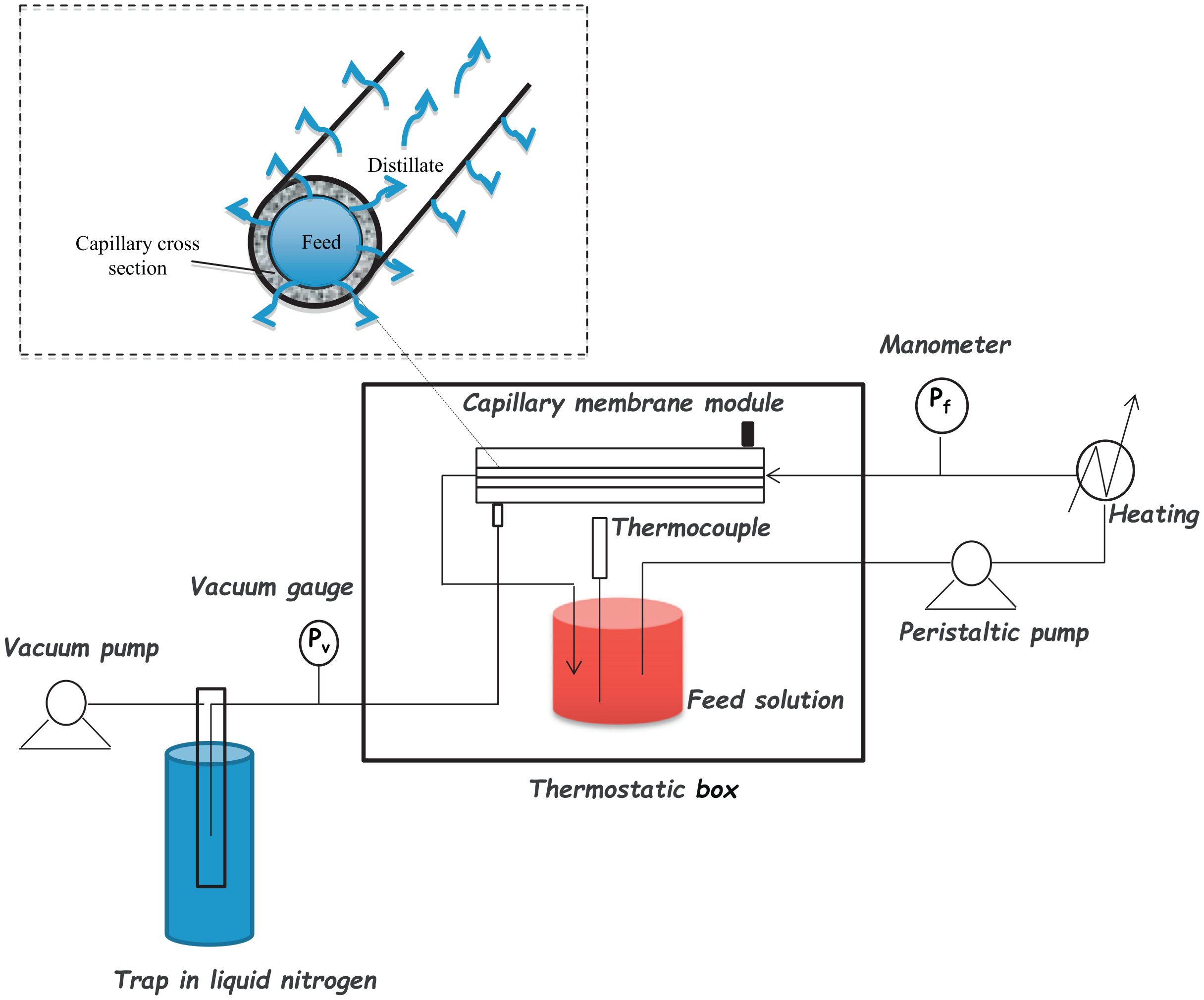

Fig. 1. Scheme of the VMD set-up. The zoom shows the distillate transport across the capillary membrane: the liquid feed is inside the capillary and the vacuum is applied outside.

two main fields of application of seawater desalination. However, the possibility to obtain not simply sweet water but high-purity water from seawater could open new perspectives for the use of seawater as source for many different applications (e.g., in the pharmaceutical or medical sectors). Therefore, the aim of this work was to identify a cleaning procedure able to lead to a high-purity distillate. For this purpose, the *DCMD* and the *SGMD* configurations that employ stripping streams (aqueous and gaseous, respectively) are not appropriate. In fact, in *DCMD* the permeate is condensed into the aqueous stream (dilution effect) and in *SGMD* the water vapor is mixed with the gas strip, so that a separation step downstream must be made, that could affect the final permeate composition. In the *AGMD* and *VMD* configurations, the produced permeate is only that evaporated from the feed side and its conductivity can be directly measured. Therefore, both configurations can be used for our scope. In this work, the *VMD* was chosen because of the easier realization of the membrane module. The zoom in Fig. 1 shows a scheme of how the distillation occurs across one of the capillary membranes assembled in the module.

2. Materials and methods

2.1. Feed solution and conductivity measurements

The salty solution used to carry out the *VMD* tests was prepared in laboratory by dissolving the following amounts of salts into deionized water, so as to simulate the seawater composition (total concentration of about 40 g L^{-1}): NaCl 23.27 g L^{-1}, Na_2SO_4 3.99 g L^{-1}, $MgCl_2 \cdot 6H_2O$ 11.28 g L^{-1}, KBr 0.095 g L^{-1}, $CaCl_2 \cdot 2H_2O$ 1.47 g L^{-1}, $NaHCO_3$ 0.1932 g L^{-1}, KCl 0.6635 g L^{-1}, and $Na_2CO_3 \cdot H_2O$ 0.0072 g L^{-1}. The conductivity of the deionized water, the feed solution and distillates were measured by a conductivity meter (EC 214 Hanna Instruments).

2.2. Capillary membranes and membrane module preparation

Commercial capillary polypropylene membranes (Membrana, ACCUREL (R) S6/2, Germany) were used to prepare the membrane modules. The main properties are: average pore size of 0.2 μm; thickness of 0.4 mm; porosity around 70%; and inner diameter of 1.8 mm.

Two identical membrane modules (M1 and M2) were assembled in laboratory, each one containing three capillary membranes into a glass shell. For each module, two tetrapak disks with three equally spaced holes to form an equilateral triangle were realized. The three capillary membranes were inserted into the first disk, blocked with parafilm, introduced inside the module glass shell and fixed at the opposite side with the second tetrapak disk. Epoxy glue (Stycast-UK), previously prepared following the instructions given by the manufacturer, was introduced via a glass pipette to seal the two module extremities. The time required for the curing of the glue was 24 h for each module extremity. Each module had a membrane area of 29 cm^2.