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Membrane fouling and cleaning in long term plant-scale membrane distillation operations

Elena Guillen-Burrieza [a], Alba Ruiz-Aguirre [b], Guillermo Zaragoza [b], Hassan A. Arafat [a,*]

[a] Institute Center for Water and Environment (iWater), Department of Chemical and Environmental Engineering, Masdar Institute of Science and Technology, P.O. Box 54224, Abu Dhabi, United Arab Emirates

[b] CIEMAT-Plataforma Solar de Almería, Ctra. de Senés s/n, 04200 Tabernas, Almería, Spain

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ABSTRACT

In this work, we first show the findings of autopsy performed on the membranes used in the Scarab AB® membrane distillation (MD) system at the solar MD pilot plant in Plataforma Solar de Almeria (PSA) in Spain. The fouling and the damage endured by the MD membranes during intermittent long-term (2010–2013) solar-powered operation in the pilot plant were assessed and characterized. Different cleaning strategies were used to remove the fouling layer and restore the membrane properties. Data regarding relevant membrane characteristics for the MD process, such as contact angle, gas permeability, porosity, liquid entry pressure, mechanical strength, etc., and their relationship with the membrane performance under MD operation were discussed and analyzed. Scanning electron microscopy (SEM) was employed to study the morphology of the fouled and cleaned membranes and characterize the membrane damage. The identified best cleaning procedure was then applied in the MD plant system at PSA. Results suggested that cleaning effectively removed a great part of the fouling and reduced the wetting of the membranes. However, this improvement was offset by the effect of inactive periods during which wetting processes were favored.

1. Introduction

Membrane distillation (MD) is a thermally driven process, in which a microporous hydrophobic membrane is used to create a liquid (feed water) and vapor (air filling the gaps) interface to cause water evaporation. MD uses a temperature gradient between both sides of the porous membrane to create a vapor pressure difference that actually drives the process. This vapor pressure difference can be established by using a coolant solution in contact with the membrane (as in direct contact membrane distillation, DCMD); using a condensing surface separated from the membrane by an air (air-gap membrane distillation, AGMD) or a liquid gap (liquid-gap membrane distillation, LGMD); using a carrying gas to transport the water vapor (sweeping gas membrane distillation, SGMD) or applying a lower pressure than the saturation pressure of the water vapor (vacuum membrane distillation, VMD). MD technology has been extensively investigated for desalination purposes in recent years. However, its large-scale industrial application has not been achieved yet and only few pilot systems are found [1–5]. Apart from the very few available studies regarding module design and optimization [6–9] there is also very little information about MD experiences under real plant conditions or the effects of long-term operation [10,11]. Also, there is a lack of information about membrane lifetime and the associated cleaning and replacement protocols. This information is essential for the economical assessment and future deployment of the technology [12,13]. One of the few pilot-plant-sized MD systems that has been reported in the literature is the solar-powered MD pilot plant located in Plataforma Solar de Almeria (PSA), Spain. The pilot plant has been used to test MD modules from five different companies [14]. One of these is the air gap MD (AGMD) flat sheet membrane module developed by Scarab AB (Sweden).Three units of the aforementioned MD module (Scarab AB) were tested from 2010 to 2013 [2,5]. The membranes used for MD purposes are perceived to be chemically stable and less likely to undergo scaling processes, due to their hydrophobic nature and the MD process itself, during which the membranes are mere supporters of the gas phase. However, distillate quality deterioration has been reported in some solar-powered MD systems [1,15,16], including the one at PSA [2]. Some authors have already pointed out scaling as a main cause of partial membrane wetting [10,17–19]. Guillen et al. demonstrated how allowing MD membranes to dry-out after operation with saline water, a practice of several solar-MD systems, is also particularly harmful to the membranes, exacerbating

* Corresponding author.
E-mail address: harafat@masdar.ac.ae (H.A. Arafat).

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wetting processes [20]. However, membrane aging under real MD operational conditions and cleaning strategies are yet to be studied.

Given the scarcity of information on fouling and cleaning plant-scale MD systems, this work aims to assess and understand the fouling issues of the Scarab AB solar-powered MD system. The study has two main objectives: (1) to characterize the damage endured by the membranes during the long-term operation and understand its relationship to the distillate quality worsening and (2) to assess different cleaning strategies, analyze the effect of each of them on membrane performance and apply the optimal protocol in the pilot system.

2. Materials and methods

2.1. The MD plant system at PSA

The test bed for evaluation of MD modules installed at PSA consists of a solar thermal field of stationary collectors (Compound Parabolic Collectors, CPC) with a total power of 150 kW_{th} at 85 °C, connected to a distribution system that can feed MD devices (test bed's details can be found in [2]). Different commercial MD modules and real-scale prototypes have been evaluated at PSA, including three MD modules manufactured by Scarab AB Company (Sweden). The three Scarab MD modules installed at PSA are flat-sheet membrane AGMD (1 mm air gap width) units with a total membrane area of 2.8 m^2 each. Flow channels are made by stacking plastic frames containing two parallel membranes (see Fig. 1).

The modules have been operating intermittently since 2010. The first major operation was carried out during four months in 2010, operating almost on a daily basis [2]. The second major operation took place between May and June 2013 and lasted 17 days. During these two periods, the modules were subjected to a daily operation of 8 h using a water solution of marine salts (NaCl) at different saline concentrations (i.e. 1 and 35 g l^{-1}) as feed. During the night, the modules were inoperative and although most of the feed solution was drained out of the modules, the membranes were probably still partially soaked in the saline feed and salt crystallization was very likely to happen.

For the purpose of this study, right after the last operation (June 2013), one of the three MD modules was dismantled to extract a fouled membrane sheet (henceforth referred to as the "fouled" membrane). The fouled membrane was sent to Masdar Institute (MI) in Abu Dhabi, UAE, along with a barely used membrane (henceforth, the "unused" membrane) that was extracted from another barely operated Scarab MD module that had to be opened and repaired by the manufacturer (Scarab AB, Sweden) right before the first set of experiments (2010). Some of the membranes belonging to that module were cleaned (DI water) and stored in dry conditions. Since it was not possible to get brand new membranes from the manufacturer, these barely used and stored membranes were considered as "unused" membranes for the purpose of this study. The unused (Fig. 2A) and fouled (Fig. 2B and C) membranes were characterized at MI by means of different techniques and subjected to a series of cleaning procedures (henceforth, the "cleaned" membranes). In September 2013, the cleaning procedure was performed in the pilot plant at PSA and the last set of MD experiments was carried out (intermittently) till January 2014.

2.2. Membranes

The membranes used in the Scarab AB module are supported (on non-woven Polypropylene (PP) backer) polytetrafluroethylene (PTFE) membranes. The membranes are thermally sealed to PP frames in pieces of 30 cm by 35 cm, as shown in Fig. 1. Fig. 2C shows the back side of the fouled membrane, apparently clean. Key properties of these membranes are shown in Table 1 (experimental details are given in the next section).

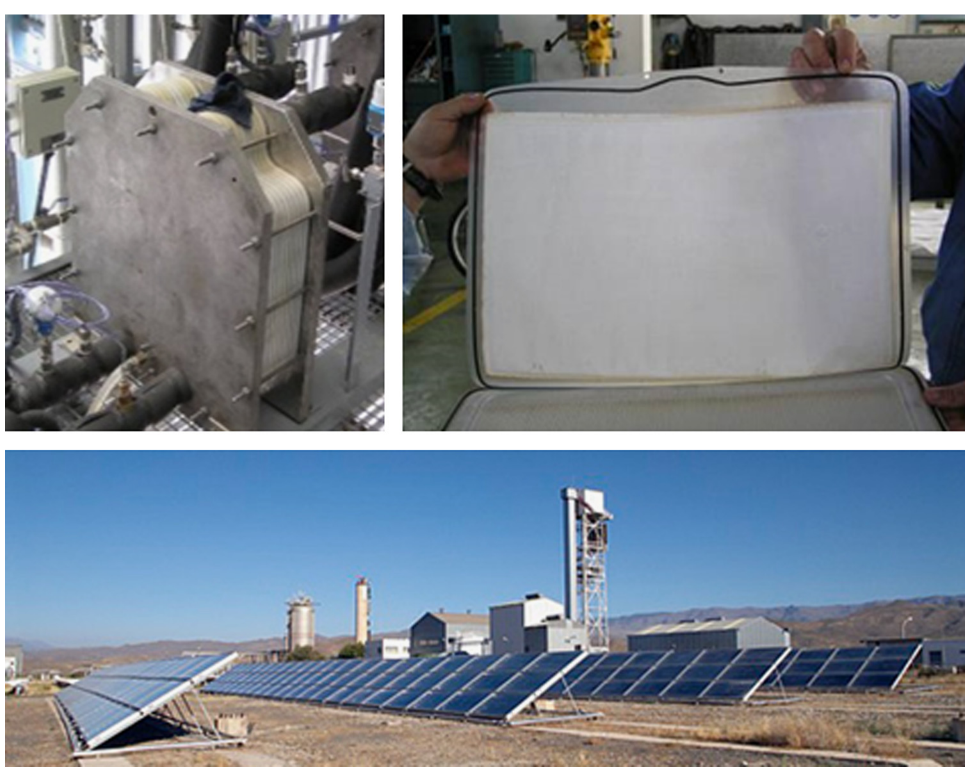

Fig. 1. AGMD Scarab AB (Sweden) modules installed at PSA (Spain) and the solar field (CPC solar collectors by AoSol, Portugal) used to power them.