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Field evaluation of membrane distillation technologies for desalination of highly saline brines

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HIGHLIGHTS

- Two MD pilot units were tested side-by-side to treat seawater and thermal brines.
- MD was able to consistently produce high quality distillate (<10 μs/cm).
- Operating conditions were optimized; unit A operated at 6.2 LMH and 52% recovery.
- Pretreatment is critical to avoid wetting and ensure proper system performance.
- Antifoam wets the MD membranes and activated carbon was an effective pretreatment.

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ABSTRACT

Membrane distillation (MD) is a hybrid thermal-membrane desalination process that uses low-grade waste heat and hydrophobic membrane to produce high quality distillate. The MD process can treat highly saline brines that other conventional desalination processes cannot treat. These unique features of the MD process make it an ideal candidate to desalinate concentrated brines from thermal desalination plants to augment fresh water production from existing facilities.
A consortium consisting of ConocoPhillips Global Water Sustainability Center, Qatar University, and Qatar Electricity & Water Company was formed to evaluate the application of MD for the desalination of concentrated brines from thermal plants. Five different MD technologies were evaluated and the two most suitable technologies were selected for field-testing. The pilot units A & B are based on multi-effect vacuum and air gap MD technologies, respectively. These units were tested side-by-side at a full-scale thermal desalination plant in Qatar. Pilot unit A showed a stable flux of 6.2 LMH under optimized conditions with excellent salt rejection (>99.9%). Pilot unit B achieved a distillate flux of 2.5 LMH and salt rejection greater than 98.9%. Overall, MD was shown to be a feasible technology to produce potable quality water from the brines discharged from thermal desalination plants.

1. Introduction

Membrane distillation (MD) is an emerging hybrid thermal-membrane desalination process that uses a vapor pressure difference, created by a temperature gradient across a hydrophobic membrane, as the driving force to produce high quality distilled water (Fig. 1) [1]. A temperature difference as low as 10 °C–20 °C between the warm and cold streams is sufficient to produce distilled water under the right conditions.

Key advantages of MD include:

- Production of distilled water
- Treatment of high salinity brines
- Lower greenhouse gas emissions
- Utilization of low grade waste heat or renewable energy resulting in lower operating costs
- Minimization of capital equipment costs by using inexpensive plastics due to the ambient operating pressures and low operating temperatures.

Other desalination processes that have been operating at a large-scale in the Middle-East include reverse osmosis (RO), multi-stage flash (MSF) and multi-effect distillation (MED).

MD has a potential niche application to desalinate concentrate brines from these processes. One reason is that the brine from thermal desalination plants contains pretreatment chemicals that assist in reducing the scaling on the MD membrane. In addition to scale minimization, using thermal brines as the feed water reduces the energy required as the feed is already significantly preheated.

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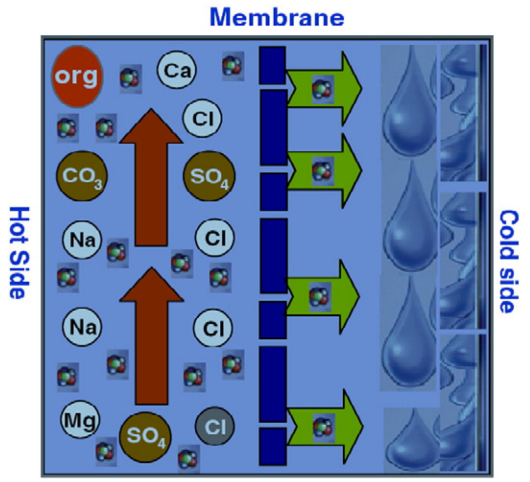

Fig. 1. Schematic of the MD process.

Furthermore, the location of thermal processes alongside with power plants results in the availability of potential low-grade waste heat (e.g. boiler blowdown, dump condenser) that can be used as the heat source. Moreover, by retrofitting existent thermal desalination plants with an MD plant, water production could be increased with minor capital investment and scarce potable water resources could be redirected for priority end uses.

Most of the MD pilot studies available in the literature focus on seawater desalination, mainly by harnessing the solar energy either by photovoltaic panels or solar collectors with heat storage mediums [2–5]. Some researchers have also studied the optimization of MD systems for specific applications [6]. An example of an optimization study is the evaluation of multi-effect MD systems where the results showed a significant increase in the process energy efficiency [7].

Researchers have also studied issues related to scaling and fouling. The deposition of calcium carbonate on the surface of MD membranes has been investigated during the demineralization of lake water using a MD bench scale system. Results showed that the morphology of the formed deposit has a significant influence on the permeate flux decline and a higher flux was obtained with less compact deposit layers [8]. Other researchers have studied the mitigation of calcite and gypsum by the application of antiscalants. Results showed that a certain type of antiscalants extends the induction period for the nucleation of gypsum and calcite without affecting membrane performance [9]. In another study, the scaling kinetics of calcium carbonate were investigated. Induction time measurements were carried out using dynamic light scattering to identify the shifting between homogeneous and heterogeneous nucleation mechanisms as a function of supersaturation. Membrane cleaning was also investigated using a two-step process consisting of citric acid and sodium hydroxide [10].

Like any emerging process, MD has potential challenges associated with it: limited experience on scale-up, process design and pretreatment issues on seawater/brine sources. In order to advance the technical knowledge in those areas, a consortium consisting of the ConocoPhillips Global Water Sustainability Center (GWSC), Qatar University (QU), and Qatar Electricity & Water Company (QEWC) was formed to evaluate the feasibility of testing the MD process at a pilot scale for desalination of brines from local thermal plants.

The primary objective of this research paper is to evaluate the performance of MD technologies on seawater and brines from thermal desalination plants. Two leading MD technologies were pilot tested to treat brines from thermal plants in Qatar. The present MD pilot study is unique as it addresses the desalination of concentrated thermal brine by evaluating two leading MD technologies side-by-side under continuous (24/7) operation at field conditions. The effect of the chemicals, from the MSF process, on the membranes was also investigated and different pretreatment options were evaluated. The critical design parameters needed to improve process efficiency at a full-scale level were identified and optimized.

2. Materials and methods

2.1. Description of pilot units

A Request for Proposal (RFP) for a 1 m^3/d pilot unit was issued to five leading MD technology providers. After a technical and commercial assessment of the bids, two pilot systems were selected for field evaluation. The two systems represent different MD technologies:

- Pilot unit A: vacuum multi-effect MD unit, with 4 effects (Fig. 2)
- Pilot unit B: air gap MD unit, single effect (Fig. 3).

Each MD system was provided with pumps, immersion heaters, water chillers, tanks and controls in a 20 ISO shipping container. Both pilot units were equipped with software that allowed remote access and control. The specifications of the pilot units are summarized in Table 1.

2.2. Modes of operation

Pilot unit A operates in a continuous flow, one pass mode. After the feed water enters the system, it is heated and then allowed to flow across the different effects in series. In the last effect, it is rejected as a concentrated stream into an external tank. Distillate is produced at each of the system's four effects and is collected in a separate external tank (Fig. 2). The latent energy released during condensation in each effect is transferred to the incoming feed of the subsequent effect. Cooling water is only applied to the final effect to remove the heat from the last effect.

Pilot unit B operates in feed and bleed mode, i.e., the feed water enters the module and the concentrated feed is recirculated back into the feed tank while the distillate is collected separately in an external tank. Therefore, the feed water gets concentrated in the feed tank and once the concentrated water reaches a predetermined conductivity value, part of the tank is drained and fresh feed is added to maintain a constant conductivity/salt concentration (Fig. 3).

2.3. Chemical analysis

The chemical compositions of the thermal brine, seawater and distillate from each of the units were analyzed using the analytical methods as listed in Table 2.

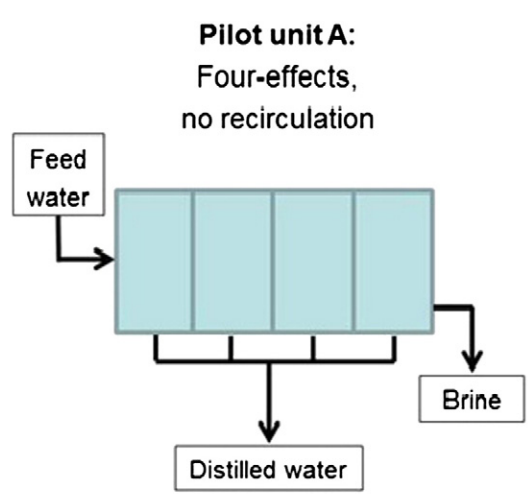

Fig. 2. Pilot unit A — schematic.