Reverse osmosis applied to soil remediation wastewater: Comparison between bench-scale and pilot-scale results

Dany Roy [a,b,*], Abdelaziz Gherrou [c], Pascale Pierre [a], Dany Landry [a], Viviane Yargeau [b]

[a] EnGlobe Corp., 4495 boul. Wilfrid-Hamel, Québec, Qc G1P 2J7, Canada
[b] McGill University, 845 Rue Sherbrooke O, Montreal, Qc H3A 0G4, Canada
[c] CTE, 696, av. Ste-Croix, Montréal, Qc H4L 3Y2, Canada

ARTICLE INFO

ABSTRACT

Bench-scale reverse osmosis results were compared to pilot-scale results to evaluate the usefulness of bench-scale studies in assessing full-scale membrane performances in the context of reusing wastewater from a novel saline soil remediation technology. Salt rejection and water recovery capacity were accurately estimated by bench-scale tests, with an average water recovery capacity of 56% *with an applied pressure of 3100 kPa* and a salt rejection of 92% at 2760 kPa. However, fouling, and concentration polarization were found to differ between scales. Concentration polarisation was 41% higher for the pilot-scale tests, which might be explained by differences in membrane configuration; coupon versus spiral-wound.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Reverse osmosis (RO) was first introduced in the 1950's as a novel filtration technology capable of separating ions from water [1]. Since then, this technology has been utilized around the world for multiple industrial applications, including drinking water purification [2], water and wastewater purification [3] maple syrup production [4], groundwater desalination [5], seawater desalination [6,7] and many more [8,9].

RO technology is constantly being improved upon, with new market applications being subsequently discovered. For each new application, studies must be conducted in order to evaluate the design parameters of the RO unit used, such as the most suitable membrane, the membrane's permeability coefficient, the membrane's rejection capacity, the flux decline that could be potentially caused by foulants and the appropriate cleaning procedure. Usually, these studies are first conducted as bench-scale (using a membrane coupon), and then as pilot- and industrial-scale (with spiral-wound membranes). While the literature dealing with the use of RO for the concentration of saline wastewater contains a wide variety of bench-scale [10–13] and pilot-scale studies [5–9,14], information

regarding the comparison between the bench and pilot-scale of an RO membrane performance are sparse [15]. As mentioned by Ladner & al., the question remains whether the bench-scale studies are useful in the determination of full-scale membrane performances [10].

In the present study, RO was investigated for a new application consisting in process water reuse for an innovative salt contaminated land remediation technology which has recently been patented [16]. With this technology, rather than performing in-situ remediation, saline soils are excavated and transported to a soil treatment facility specifically designed for their treatment. While offering more efficient salt removal than conventional technologies, this soil remediation technology still produces a large volume of highly saline process wastewater (3–40 g/L of total dissolved solids) that is currently disposed of by deep well injection [17]. The distance between the remediation site, the water supply and the disposal options, and costs associated with this distance water transportation and supply/disposal costs) set geographical limits and thus dictate the economical applicability of the technology. One option to extend such geographical limits, is to minimize water usage by combining the new remediation technology with a RO unit. Since very little data concerning the concentration and reuse of saline soil treatment wastewater was available in the literature [9], bench-scale, as well as pilot-scale tests were performed in order to determine the RO unit design parameters for this particular application.

* Corresponding author at: EnGlobe Corp., 4495 boul. Wilfrid-Hamel, Québec, Qc G1P 2J7, Canada.
E-mail address: dany.roy2@mail.mcgill.ca (D. Roy).

1.1. Objectives and scope of work

In the present study, we evaluated the relevance and usefulness of bench-scale RO studies in the assessment of full-scale membrane performance for a specific application, while subsequently providing a method for assessing membrane performances. The synthetic saline water used in this study did not contain organic matter. Therefore, organic fouling of the membranes is not discussed and the findings presented in this manuscript only apply to effluents with a mineral charge. The main parameters considered for the comparison were the water recovery capacity, the transport parameters and salt rejection capacity, as well as the mineral fouling of the membrane.

2. Material and methods

2.1. Membranes

Previous tests led to the selection of the BW-30 membrane for the filtration of saline soil treatment wastewater. BW-30 reverse osmosis membranes were obtained from Filmtec (MI, USA) a wholly owned subsidiary of the Dow Chemical Company. Membranes were received as 4 in. spiral wound ($7\,m^2$ of membrane surface) with fiberglass outer wrap. To get membrane coupons for lab tests, a spiral wound was cut to fit the bench-scale RO cell. The BW-30 membrane manufacturer's data are presented at Table 1.

2.2. Bench-scale RO system

The laboratory set-up was designed as presented in the diagram in Fig. 1. The key components were the membrane test cell (1), the high-pressure pump (2) and the feed water reservoir (3).

Experiments were conducted using a commercially available bench-scale membrane test cell (Sepa CF, GE Osmonics). The flow channels on each side of the membrane were filled with a mesh

Table 1
BW-30 membrane manufacturer's data.

Operating limits	
Membrane type	Polyamide thin–film composite
Maximum operating temperature	45 °C
Maximum operating pressure	4100 kPa
pH range (operation)	2–11
pH range (cleaning)	1–12
Membrane specifications[a]	
Membrane permeation	50 LMH
Salt rejection	99.5%

[a] Based on the following conditions: 2000 ppm NaCl, 1550 kPa, 25 °C and 15% recovery.
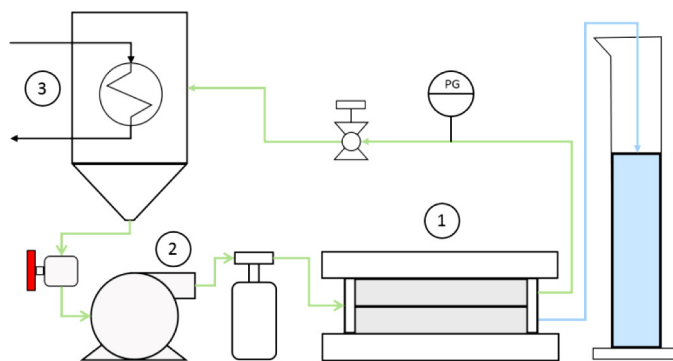

Fig. 1. Bench scale reverse osmosis set-up.

spacer to simulate the hydrodynamics of a spiral-wound membrane element [11]. These mesh spacers were cut directly from the spiral wound. Feed water was circulated on the active layer side of the membrane through ten round 4.7 mm diameter openings. The effective surface area of the membrane was $149\,cm^2$ (10 cm wide and 15 cm long with rounded corners). Permeate was then collected through another ten round 4.7 mm diameter openings located in the center of the membrane coupon.

The high-pressure feed water pump was a Hydra-Cell positive displacement pump with a diaphragm design. In order to stabilize the pressure, a bladder accumulator was installed at the outlet of the pump. Pump speed was set manually by the operator. Pressure in the system was adjusted manually with a globe valve and measured with an analog pressure gauge.

The feed water reservoir was a double shell stainless steel tank with a capacity of approximately 4 L. To ensure adequate cooling, temperature control was provided by a heat exchanger, which circulated a cooled glycol solution inside the reservoir walls.

The permeate flow was calculated by collecting a new sample at the outlet of the cell every 10 min. The volume of the sample was measured with a 50 mL graduated cylinder and recorded. The electrical conductivity of the sample, and the recirculated feed, was measured using a Thermo Scientific Orion 013005MD conductimeter.

2.3. Pilot-scale RO system

Pilot-scale experiments were conducted using a small-scale commercial RO unit (Turbo Compak, Darveau) designed as presented in the diagram in Fig. 2. The key components were the feed pump (1), the pre-treatment system (2), the high-pressure dual pump (3), the RO membrane (4), the heat exchanger (5) and the feed water reservoir (6).

Water was supplied to the system by a 0.37 kW (1/2 hp) peristaltic pump. Feed water was pretreated through a two-step filtration system: a washable 24 μm mesh filter and a 5 μm disposable cartridge filter. Filter fouling was monitored with 2 analog pressure gauges located upstream and downstream of the filters. When the pressure difference was over 70 kPa (10 psi), the mesh filter was washed and the cartridge filter was replaced.

The high-pressure dual pump combines a multi-stage centrifugal submersible pump capable of a maximum pressure of 3105 kPa (450 psi) to a centrifugal recirculation pump with a capacity of 110 L/min. The pump was manually activated and powered by a 2.24 kW (3 hp) motor operating at 230 V. The recirculation ratio was controlled manually by a globe valve, which also controlled the pressure in the system. This pressure was measured with an analog pressure gauge located at the outlet of the membrane.

In order to operate the system in recirculation mode as shown at Fig. 2, a heat exchanger was installed on the concentrate conduit in order to maintain the feed at a constant temperature. A custom-made shell and tube heat exchanger was assembled. Tap water was used as coolant and the overall heat-transfer coefficient of the heat exchanger was evaluated at $430\,W/m^2{}_*°C$.

Temperature in the system was monitored with type T thermocouples. Data acquisition was done by an OM-CP-OCTTEMP-A data logger from OMEGA. The permeate and the concentrate flows were measured with analog in-line flow meters. Electrical conductivity was measured using an OAKTON Con 6 Acorn Series conductimeter.

2.4. Synthetic saline wastewater

Due to the limited quantity and the associated procurement cost of saline soil treatment process wastewater at the time of these experiments, both lab- and pilot-scale tests were performed using synthetic saline wastewater imitating the process wastew-