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Dilution of seawater using dewatered construction water in a hybrid forward osmosis system

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ABSTRACT

In this study, dewatered construction water was used for the first time as the feed solution in a combined pretreatment-forward osmosis process to dilute seawater (i.e. draw solution) for further desalination. It was found that at a feed solution and a draw solution flow rate of 2.2 L min^{-1} gave the optimum membrane flux with minimal fouling effects. The addition of a spacer in the membrane feed side was effective at low flow rates (0.8 and 1.5 L min^{-1}). The feed solution was then pretreated using two methods: settling and multimedia filtration and used in the forward osmosis unit at a low flow rate of 0.8 L min^{-1} using a spacer at the feed side. Results revealed a significant increase in the forward osmosis membrane flux by 64.3% when multimedia filtration was carried out with a flux reduction of 7.7%. While the settling method achieved only 13.5% increase in the permeate flux and 12.5% flux reduction. The multimedia filtration process removed most of the particles that would cause fouling which resulted in an elevated and more consistent membrane flux. Results also showed that the water flux was 1.3 times higher when the membrane's active layer was facing the draw solution than when it was facing the feed solution. Cost analysis showed that forward osmosis treatment of dewatered construction water was 7.88 $.$day^{-1}$ and it was slightly cheaper when the forward osmosis operates in the pressure retarded osmosis mode.

1. Introduction

Dewatered construction water (DCW) is a by-product wastewater generated at construction sites. DCW has low salinity (i.e. conductivity of 3456 μS/cm), trace concentration of heavy metals and low total suspended solids (i.e. turbidity of 350 NTU) (Table 1). Therefore, DCW requires minimum treatment before discharge. Building and construction works in Qatar have resulted in the generation of large amounts of DCW which usually get treated on site before being discharged to the sea or injected into deep aquifers. Alternatively, DCW can be reclaimed for reuse on site or for general use such as irrigation at a lower cost as to the use of desalinated water because of its low salinity and pretreatment requirements (Angel et al., 2015; Powers et al., 2007). This study investigates the possibility of using DCW as a feed solution (FS) in forward osmosis (FO) to reduce the salinity of seawater which is used as the draw solution (DS) in the process. The seawater will get diluted before further desalination by reverse osmosis (RO) at a reduced cost compared to the conventional RO desalination process. The proper reuse of DCW is expected to reduce the adverse environmental impact of discharging such waters to the environment.

Forward osmosis is a new emerging osmotic process that involves a semipermeable membrane separating two solutions of different concentrations; the membrane permits water molecules to pass through but has high rejection to ionic species. This process causes the concentrated solution termed as the draw solution with high osmotic pressure to become more diluted and the less concentrated solution which is called feed solution with low osmotic pressure to become more concentrated (Shiqiang et al., 2017; Qasim et al., 2015). Unlike reverse osmosis (RO), FO does not require the application of hydraulic pressure; instead it only utilizes the osmotic pressure difference with minimum energy requirements and lower membrane fouling (Shiqiang et al., 2017; Zhao et al., 2012).

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Table 1
Chemical characteristics of the DCW used as the FS in the FO process.

Parameter (unit)	obtained value	Parameter (unit)	obtained value	Parameter (unit)	obtained value
pH	7.59	Nitrite-N (ppm)	0.182	Mg (ppm)	80
Turbidity (NTU)	350	Hardness (ppm)	1273	Mn (ppm)	<0.05
COD (ppm)	17	P (ppm)	1.22	Mo (ppm)	<0.05
Alkalinity (ppm)	149	As (ppm)	<0.05	Na (ppm)	297
$HCO3^-$(ppm)	181	B (ppm)	0.6718	Ni (ppm)	<0.05
SO4 (ppm)	1020	Ba (ppm)	0.0572	Pb (ppm)	<0.05
CL (ppm)	441	Ca (ppm)	378	Sb (ppm)	<0.05
Ammonia Nitrogen-N (ppm)	1.615	Co (ppm)	<0.05	Se (ppm)	<0.05
Nitrate-N (ppm)	3.1	Cr (ppm)	<0.05	Sr (ppm)	9.648
EC (μS/cm)	3456	Cu (ppm)	<0.05	V (ppm)	0.247
K (ppm)	26.4	Fe (ppm)	<0.05	Zn (ppm)	<0.05

Several research groups have implemented new concepts on the use of FO technology combined with other processes for the treatment of wastewater. For instance, Cornelissen et al. (2008) developed an osmotic membrane bioreactor (OMBR) for the recovery of wastewater which combines between activated sludge treatment and forward osmosis membrane separation. Instead of using the ultrafiltration or microfiltration membrane as in conventional membrane bioreactors (MBRs) the FO membrane was used directly in contact with the activated sludge. As such, high water fluxes were obtained using 0.5 M NaCl draw solution with low fouling propensity. A hybrid FO-RO process implemented by Cath et al. (2010) was used to transfer water from impaired water source such as wastewater with low salinity to seawater via osmotic gradient in order to dilute the seawater before further desalination with RO process (SWRO). The authors demonstrated that this approach lowers the energy use for the SWRO desalination, allows recycling of wastewater with recoveries of water up to 63%, reassures multi-barrier protection of drinking water and reduces RO membrane fouling due to reduced pollutant load in the diluted seawater. Thiruvenkatachari et al. (2016) applied integrated FO-RO system for coal mine wastewater treatment. FO process was able to recover 80% of the total volume of brackish mine wastewater and producing a dischargeable quality treated solution. Reversible FO fouling was reported by flashing the membrane with clean water to restore water flux. Hickenbottom et al. (2013) evaluated FO process for the treatment of drilling wastewater. Experimental results showed high rejection rate of FO to organic and inorganic matters and capability to achieve >80% recovery rate without membrane fouling. Impact of spacers on the rejection rate of trace antibiotic in wastewater was investigated by Liu et al. (2015). The rejection rate of antibiotic by FO increased when spacer was added and the draw solution was facing the membrane active layer. Researchers concluded that adding spacer promoted turbulence flow that improved the back diffusion of antibiotics from the support layer to the bulk solution. Boo et al. (2013) investigated fouling control in FO for wastewater reclamation using seawater or RO brine as draw solutions. Results revealed that support layer fouling by seawater or RO brine was insignificant while fouling of the membrane active layer occurred due to the accumulation of fouling matters. Fouling minimization by controlling hydrodynamics parameters such as increasing feed flow velocity, employing pulsed flow and using spacers effectively reduced the FO fouling.

In this study, dewatered construction water (DCW) is used for the first time as the feed solution in a combined pretreatment-FO process to dilute seawater for further desalination. The objective of this study is to determine the best pretreatment requirements of DCW for FO process and to study the effect of design and testing parameters such as flow rates of FS and DS, orientation of membrane and the placement of spacer on the FO process. Two pretreatment processes are performed namely, sedimentation and multimedia filtration. For the first time, the impact of membrane orientation on the cost of the FO process was estimated in this study. Furthermore, the study investigated the effect of design and testing parameters on the performance and cost of the FO process.

2. Materials and setup

2.1. Feed solution and draw solution characterization

Dewatered construction water samples were collected from a construction site in Doha City, State of Qatar. Table 1 shows a summary of the chemical characteristics of the DCW to be used as the feed solution in the FO process. The feed water conductivity is 3456 μS/cm compared to 54000 μS/cm for a standard seawater (35000 ppm). Sweater draw solution was made of 0.6 M Sodium Chloride solution. The chemical analysis were performed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) (ICP-OES Optima 5000 series) and Ion Chromatography (IC) (Metrohm 850).

2.2. FO unit setup

A schematic diagram for the experimental set up is given in Fig. 1. Sepa CF forward osmosis cell unit, supplied by SteritechTM Corporation, has been used in this study. The outer dimensions of the cell are $9 \times 12 \times 8.5$ cm. The cell is formed of two distinct compartments that are separated by an FO membrane. One compartment permits the flow of draw solution and other compartment is used for the feed solution. Both draw and feed solutions will flow in a counter current mode.

Two cup style feed tanks made of stainless steel with a 9 L capacity, also supplied by SteritechTM Corporation, were used for the DCW feed solution and the seawater draw solution. Moreover, two Cole-Parmer Micro-pumps A Mount Gear pump with Console Drive, PEEK Gears/PTFE seals were used to circulate and control the draw and the feed solutions flow. Two flow meters have been installed in the draw as well as the feed lines in order to measure the desired flow rates. A magnetic stirrer was used to ensure complete homogeneity in the DS and FS tanks.

Initially, the volume of the draw and the feed solutions were 6.0 L each. Solutions leaving the FO cell were recycled back to their respective tanks. The FO unit was operated for almost 1000 min for each experimental run. A new membrane was inserted in the FO cell after each run.

2.3. FO membrane

This study used a cellulose tri-acetate (CTA) forward osmosis membrane supplied by Hydration Technology Innovation (HTI). The