Production of an engineered fertilizing solution from treated waste water using forward osmosis

Mhd. Ammar Hafez[†], Alaa H. Hawari[†, ‡], Ali Altaee[††]

[†]Department of Civil and Architectural Engineering, Qatar University, P.O. Box 2713, Doha, Qatar.

[††]School of Civil and Environmental Engineering, University of Technology in Sydney, 15 Broadway, Ultimo, NSW 2007, Australia

[‡]Corresponding author

Abstract

Treated sewage effluent (TSE) contains high concentrations of total dissolved solids and nutrients, which makes TSE unsuitable for direct use for irrigation. In this study, forward osmosis (FO) is utilized to produce a fertilizing solution from TSE that can be directly used for irrigation. An engineered fertilizing solution was used as a draw solution while the feed solution was TSE in the forward osmosis process. The engineered fertilizing solution is made of 0.5 M NaCl and 0.01 M of Diammonium phosphate [$(NH_4)_2HPO_4$]. The effect of feed solution and draw solution flow rate on the permeate flux is studied. Furthermore, the impact of the membrane orientation on the permeate flux is also studied. Results showed that the highest membrane flux was 13.2 LMH, achieved at a flow rate of 2 LPM for the feed solution and the draw solution. Moreover, at 2 LPM flowrate, when the feed solution is facing the active layer of the membrane (FO mode) showed 114% higher permeate flux than when the draw solution is facing the active layer (PRO mode).

Keywords: Forward osmosis; fertilizing solution; Irrigation water; Membrane flux; waste water.

1. Introduction

Water scarcity is one of the most challenging problems that affect agriculture worldwide, especially in arid areas. The United Nations estimates that agriculture accounts for 70% of the water usage around the world [1]. World population is approximated to be 9 billion by 2050, which will increase demands on the water resources and food resources [2]. Integrated water resources management has become a must practice, of which wastewater reuse is a critical element. Wastewater reuse often requires Reverse Osmosis (RO) or Nanofiltration (NF) treatment for the removal of TDS and organic matters [3]. However, fouling of RO and NF membranes treating wastewater was reported due to the interaction of organic and inorganic matters with the membrane surface. As such, new research studies proposed Forward Osmosis (FO) membrane for the treatment of wastewater and seawater because of its low fouling propensity and high rejection rate

[2, 4, 5]. FO process was also suggested for irrigation water supply using wastewater feed solution because of high membrane resistance to fouling [5].

Recently, scientists proposed forward osmosis (FO) for the supply of fertilizing solution which will provide the required nutrients to plants [2]. Sherub et al.[2] studied the possibility of producing fertilizing water from brackish groundwater by FO followed by Nanofiltration (NF). The nanofiltration process was proposed for the regeneration of the draw solution. The NF process was more efficient to lower the nutrients concentration in fertilizing solution when the concentration of groundwater was relatively low. A maximum water flux of 10 $L/m^2.h$ was achieved using brackish groundwater as the feed solution and a 1 M calcium ammonium chloride as the draw solution. For high salinity groundwater, NF process was inefficient to produce a fertilizing solution within the desirable range of nutrients concentration. A further post-treatment was required to reduce the nutrients concentration before the application of the fertilizing solution on crops. Using a post-treatment process after the NF process will compromise the cost-effectiveness of the fertilizing solution. In order to avoid a post-treatment stage, the RO process can be operated using an engineered fertilizing draw solution. The feed solution will dilute the engineered draw solution and produce an engineered fertilizing solution.

The fertilizer drawn forward osmosis (FDFO) has been studied so far through computational, lab and pilot scale experiments using different feed and draw solutions and regeneration processes (i.e. UF and NF). This paper evaluates the performance of a FO system to produce a fertilizing solution for irrigational purposes. The feed solution in the FO process was treated sewage effluent (TSE) supplied from a wastewater treatment plant in Doha, while the draw solution was and engineered draw solution with concentration of 0.5M NaCl and 0.01M diammonium phosphate ($(NH_4)_2HPO_4$). The reason behind selecting these salts to be in the draw solution is that NaCl was the primary chemical agent of high osmotic pressure (i.e. high driving force is the FO process) and the diammonium phosphate was the chemical agent of nutrients source. In this paper, the effect of feed solution and draw solutions' flowrate and orientation of the membrane on permeate flux will be studied.

2.0 Materials and Setup

2.1 Forward Osmosis Setup

A schematic diagram for the FO-RO hybrid system is shown in Figure 1. For the FO system, a Sterlitech CF042 Delrin membrane cell was used. The cell dimensions are 12.7 x 8.3 x 10 cm with an active inner dimension of 4.6 x 9.2 cm and a slot depth of 0.23 cm. The membrane was placed inside the cell so that the feed and the draw solutions would flow from each side separately. Two tanks with a capacity of 6 L were used for the feed and the draw solutions. Two Cole-Parmer gear pumps (0.91 ml/rev) were used to circulate the feed and the draw solutions through the membrane cell. Two flow meters (Sterlitech Site Read Panel Mount Flow Meter) have been used to measure the flow rate of the feed and the draw solutions. A digital balance (EW-11017-04 Ohaus Ranger™ Scale) was used to measure the mass change of the DS in order to calculate the water flux in the FO system. The volume of the feed and the draw solutions was 4 L each at the beginning of each experiment. The solutions going out from the FO cell were recycled back into the same tanks with an operating time of 180 min for each experiment. A new membrane was used for each trial. A TFC FO membrane (Hydration Technology Innovation-USA) with a structural parameter value of 215 microns was used. The used FO membrane has a high rejection rate for dissolved solids, bacteria and viruses. The membrane was cut to be placed inside the cell with dimensions of 5.75 x 11.5 cm with an active area of 42.32 cm^2 (i.e. 4.6 cm x 9.2 cm). The membrane was washed for 20 minutes with distilled water for pre-conditioning and removal of any chemicals from its surface. A 1 mm Sepa CF high fouling spacer (8 x 3.5 cm) was always placed on the support side of the FO membrane.

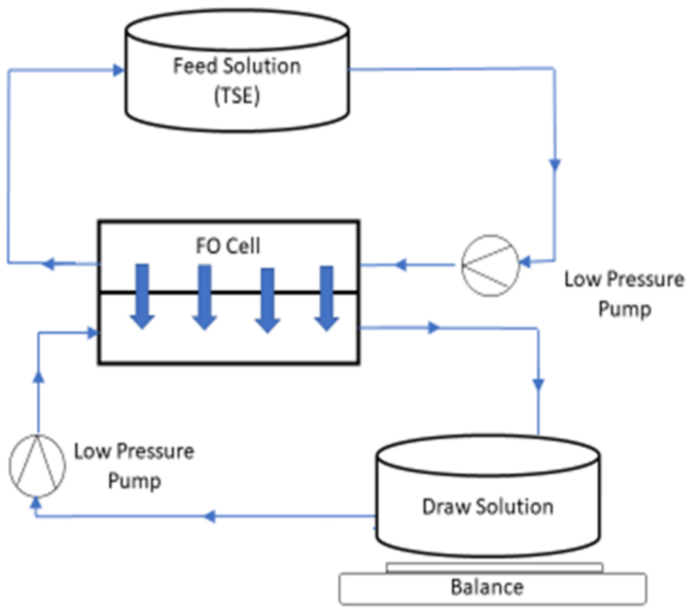

Figure 1: The hybrid FO-RO system used to produce the engineered fertilizing solution.

2.2 Feed solution and Draw Solution

The feed solution (FS) in the FO system was treated sewage effluent (TSE). Treated sewage effluent samples were collected after a membrane bioreactor (MBR) unit from Lusail wastewater treatment plant located in Doha, Qatar. The characteristics of the collected TSE samples are summarized in Table 1. The salinity of the TSE was found to be within brackish water range and would require further treatment before being able to use it for irrigation. The draw solution was the engineered fertilizing solutions (EFS). The EFS was composed of 0.5M NaCl and 0.01M (1419 mg/L) diammonium phosphate ($(NH_4)_2HPO_4$). The diammonium phosphate was added to the draw solution as a nutrient source in the product water while NaCl is the source of osmotic pressure across the FO membrane. This approach reduces the concentration of ammonium and phosphate in the product water due to the rejection rate of ammonium. The concentration of nutrients in the product water would be low enough and can be used directly without further dilution [6]. The product water from the hybrid system is supposed to be used directly for irrigation purposes.

Table 1: *Characteristics of the treated sewage effluent (TSE) collected form a wastewater treatment plant in Doha, Qatar.*

Parameter (unit)	Value	Standard Method
pH	6.9	APHA 4500-H+ B. Electrometric Method
Temperature (C)	22.2	APHA 2550 TEMPERATURE
Turbidity (NTU)	0.84	APHA 2130 B. Nephelometric Method
COD (mg/L)	206.3	APHA 5220 D. Closed Reflux, Colorimetric Method
Conductivity (mS/cm)	5.12	APHA 2510 B. Conductivity
TDS (mg/L)	2816	APHA 2540 C. Total Dissolved Solids Dried at 180°C
TSS (g)	0	APHA 2540 D. Total Suspended Solids Dried at 103–105°C
TP(mg/L)	7.583	1. APHA 4500-P C. Vanadomolybdophosphoric Acid Colorimetric Method 2. APHA 4500-P E. Ascorbic Acid Method
NH_4(mg/L)	0.492	ASTM D 1426 – 03 Standard Test Methods for Ammonia Nitrogen In Water

3. Results and Discussion

The study investigated the impact of the flow rates of the DS and the FS and the membrane orientation on the membrane flux. The FS was TSE and two types of draw solutions were examined (i.e. 0.5M NaCl and EFS (0.5M NaCl and 0.01M diammonium phosphate ($(NH_4)_2HPO_4$)). It can be seen from Figure 2 that the membrane flux decreased with time in both membrane orientations. The decrease of the membrane flux was due to the dilution of the draw solution and FO membrane fouling. In fact, TSE contains trace concentration of organic matters, which are source of contamination and FO membrane fouling when they accumulate on the membrane surface [7-10]. It can be also seen from Figure 2 that the average membrane flux increased as the flow rates of the draw solution and the feed solution increased in both membrane orientations. As shown in Figure 2 (b), in the FO mode, the average membrane flux increased from 11.0 L/m^2.h to 13.2 L/m^2.h as the flow rates of the draw and the feed solutions increased from 1.2 L/min to 2 L/min, respectively. In the PRO mode the average membrane flux increased from 8.0 L/m^2.h to 10.5 L/m^2.h as the flow rates of the draw and the feed solutions increased from 1.2 L/min to 2 L/min, respectively. The increase of the membrane flux with the increase of the flow rates of the draw and the feed solutions is due to the minimized concentration polarization effect at higher flow rates [11]. Concentration polarization plays a major role in decreasing the osmotic effect across the FO membrane which would decrease the membrane flux [12, 13]. Increasing the flow rates of the draw and the feed solutions would increase the turbulence around the membrane surface, which in turn reduces the effect of concentration polarization and increases the mass transfer coefficient [14].

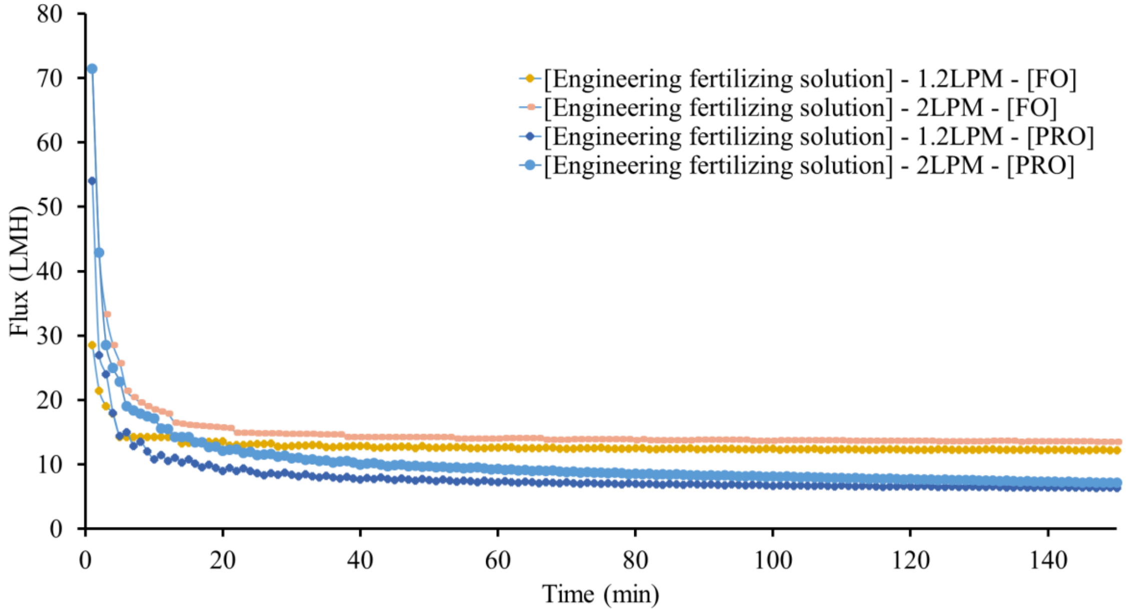

Figure 2: Membrane flux using EFS as draw solutions in FO mode and PRO mode at different DS and FS flow rates

Figure 3 shows average membrane flux at 1.2 LPM and 2 LPM flowrate when operated at FO and PRO mode. When the osmotic pressure was calculated using the Van't Hoff's equation, the osmotic pressure of EFS was found to be 58 bar [6]. Figure 3 also shows that the average membrane flux in the FO mode was always higher than that in the PRO mode for both the 0.5M NaCl and EFS draw solutions. In the PRO mode, the support layer faces the feed solution, which in this case was the TSE. Using such a feed solution with a high concentration of organic matter could promote membrane fouling due to the accumulation of foulants on the rough support layer [15]. The rough surface of the support layer would provide more surface area for the foulants to reside on [16]. The SEM images show that high concentration of foulants accumulated on the surface of the support layer when it is facing the TSE feed solution (PRO mode) compared to when the support layer was facing the EFS (i.e. FO mode) (Figure 4). Similar findings were reported in the literature where the FO mode resulted in a higher membrane flux compared to the PRO mode [7, 17]. In general, the FO mode is recommended when the feed solution contains high concentration of fouling materials such as TSE. While the PRO mode is recommended when using a feed solution with low concentration of fouling materials [7].

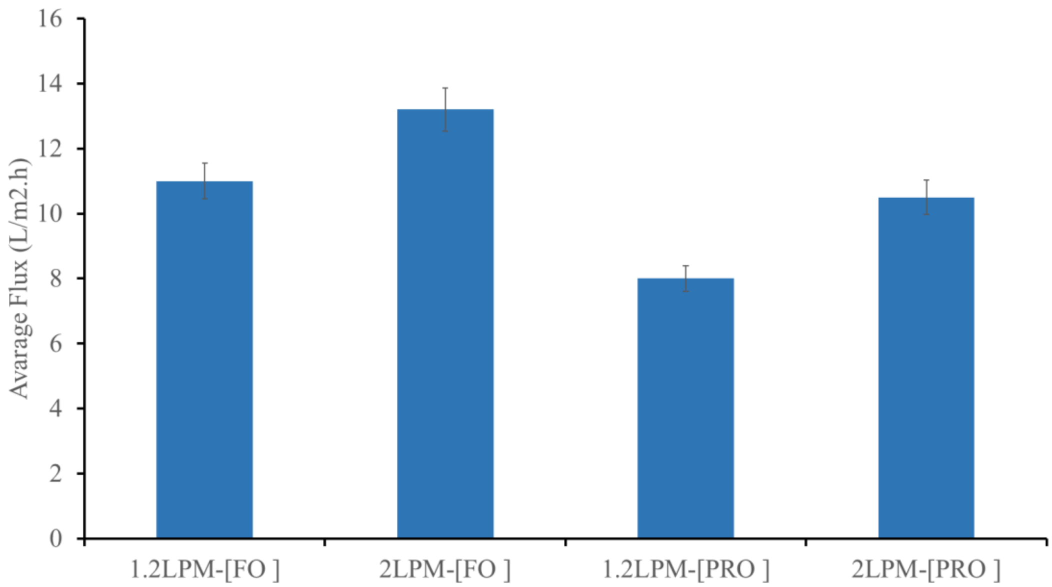

Figure 3: Avarege membrane flux in FO mode and PRO mode at different DS and FS flow rates.

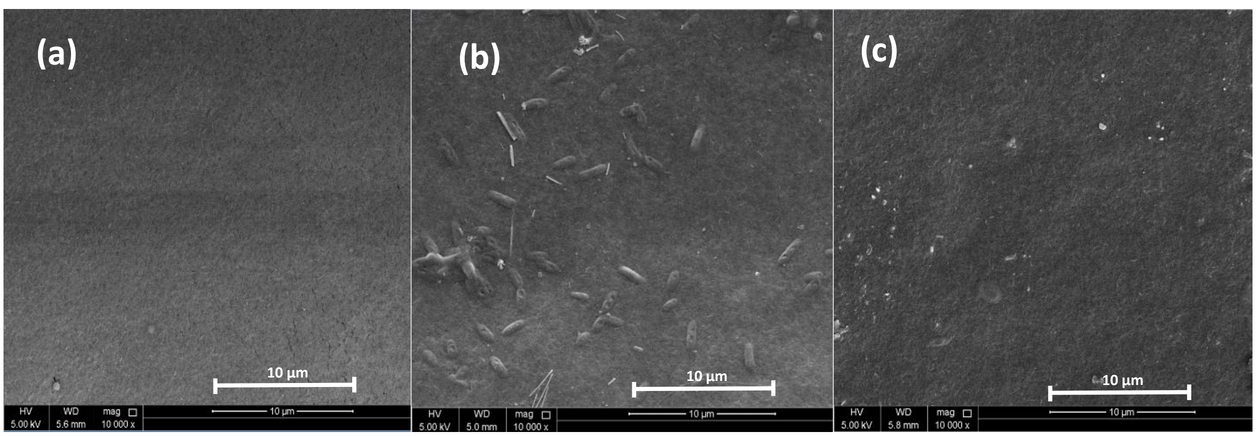

Figure 4: *Scanning Electron Microscopy (SEM) images of the FO membrane at FS and DS flow rates of 1.2LPM, using EFS as draw solution and TSE as the feed solution (a) Clean Support layer, (b) Support layer facing the feed solution (PRO mode), (c) Support Layer facing the draw solution (FO mode). The SEM images are at 10,000x magnification.*

4. Conclusions

This paper evaluated the performance of a FO process to produce a fertilizing solution applicable for irrigation purposes. In the FO process, real treated sewage effluent (TSE) was used as the feed solution and a mixture of 0.5M NaCl and 0.01M Diammonium phosphate ($(NH_4)_2HPO_4$) was used as draw solution. The impact of the flow rate of the feed solution and the draw solution, the membrane orientation (i.e. FO mode and PRO mode) on the membrane flux were tested. The average membrane flux in the FO mode was always higher than that in the PRO mode by 114%. Moreover, the highest membrane flux was 13.2 LMH, achieved at a flow rate of 2 LPM for the feed solution and the draw solution. If needed, the produced fertilizing solution can be further treated by using reverse osmosis.

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