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Application of Forward/Reverse Osmosis Hybrid System for Brackish Water Desalination using El-Salam Canal Water, Sinai, Egypt, Part (1): FO Performance

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Abstract. This paper is the first part of two papers focus on the investigation of a forward osmosis – reverse osmosis hybrid process to co-treat brackish water and El-Salam Canal water in Sinai, Egypt. By using this hybrid process, brackish water can be diluted before desalination, hence reducing the energy cost of desalination. Simultaneously, contaminants present in the El-Salam Canal water are prevented from migrating into the product water through the forward and reverse osmosis membranes. The main objective of this part is to investigate the performance of the forward osmosis (FO) system at different draw solution concentrations comparable to the ground water in Sinai. It was found that the FO water fluxes are low and not promising to be economically applied. To improve the FO performance with El-Salam canal water, ammonium bicarbonate was added to water wells to increase the osmotic pressure of draw solution.

Keywords: Forward osmosis, Reverse osmosis, Membrane desalination, Impaired water, Brackish water, El-Salam Canal.

1. Introduction

Due to the fact that water demand is larger than the conventional supply, the utilization of non-conventional water resources became evident. The Nile River is the main source of fresh water in Egypt, supplying 95 percent of its overall water usage. However, the country is faced with the threat of severe water shortage in the next decade. According to a November 2012 report produced by Future Directions International, Egypt experiences an annual water shortfall of 7 billion cubic meters, and domestic water demand in the country is expected to increase by 25 percent in 2025 [1]. Accordingly, exploration of novel approaches to increase the country's supply of fresh water in order to meet this constantly rising demands imperative. Currently, Egypt's supply of fresh water relies on exploiting groundwater, reuse of treated wastewater, recycling of irrigation and agricultural drainage water, and desalination, which is the removal of salt from seawater and brackish water to obtain fresh water suitable for agriculture and human consumption. RO has emerged as the leading technology for future desalination facilities because of its relatively low energy consumption and produced water cost compared to thermal desalination technologies [2]. However, the real and perceived costs and energy requirements of its high pressure pumping continue to be a barrier to its implementation [3], [4]. FO is an engineered osmotically driven membrane process that uses osmotic pressure of concentrated solutions to extract clean water from diluted solution. In a new approach, FO uses a saline stream (seawater or brackish water concentrate) as draw solution to extract water from a source of impaired water [5], [6]. The driving force for water flux in FO is the difference in osmotic pressure between two water solutions, the saline water and the impaired water, and not hydrostatic pressure as in RO or NF. As such, the energy cost associated with FO is very low. A combined desalination process using emerging FO technology coupled with RO could potentially reduce the energy consumption of the desalination process, and thus, lower barriers to its implementation.

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El-Salam Canal water is a mixture of water from river and agricultural drainage (2.11 billion m^3/y of fresh Nile water mixed with 1.905 billion m^3/y of water from Bahr Hadous and 0.435 billion m^3/y of El-Serw drainage). The ratio of Nile water to drainage water is about 1:1. This ratio is determined to reach total dissolved solids (TDS) not more than 1000– 1200 mg/l to be suitable for cultivated crops. Since the catchment area of Bahr Hadous and Serw drains are located in highly populated area, they are susceptible to pollution from legal and illegal dumping of domestic and industrial wastewater which makes it not acceptable for animals drinking or irrigation purposes [7], [8]. This paper focus on the investigation of a FO – RO hybrid process to co-treat the brackish water (wells around the canal) and El-Salam Canal water at the same time. By using this hybrid process, brackish water can be diluted before desalination, hence reducing the energy cost of desalination, and simultaneously, contaminants present in the El-Salam Canal water are prevented from migrating into the product water through two established barriers, the FO membrane and the RO membrane. The main objective of this part is to investigate the performance of the FO system at different draw solution concentrations comparable to the ground water in Sinai.

2. Materials and Methods

2.1. Experimental set-up

A schematic drawing of the designed bench scale system is illustrated in Fig. 1. Feed solution (FS) and draw solution (DS) were re-circulated from their respective tanks at 0.857 l/min through the FO membrane cell and back to the tanks using a piston dosing pump positive stroke spring return. The membrane cell consists of CFO42 stainless steel 316 FO style cell with active membrane area 56 cm^2, cell has symmetric channels on both sides of the membrane, each channel with dimensions of 2, 95, and 45 mm for height, length and width, respectively. The DS and FS flowed counter- currently in each channel on both sides of the membrane, both of which were controlled independently by a micro pump (ETATRON D.S. S.P.A.). The DS tank will be placed on an analytical balance (Vibra, Pine Brook, NJ), and the rate of change of the DS weight was recorded and used for calculation of water flux through the membrane. The conductivity meter Myronn L Ultrameter was used for TDS measurements.

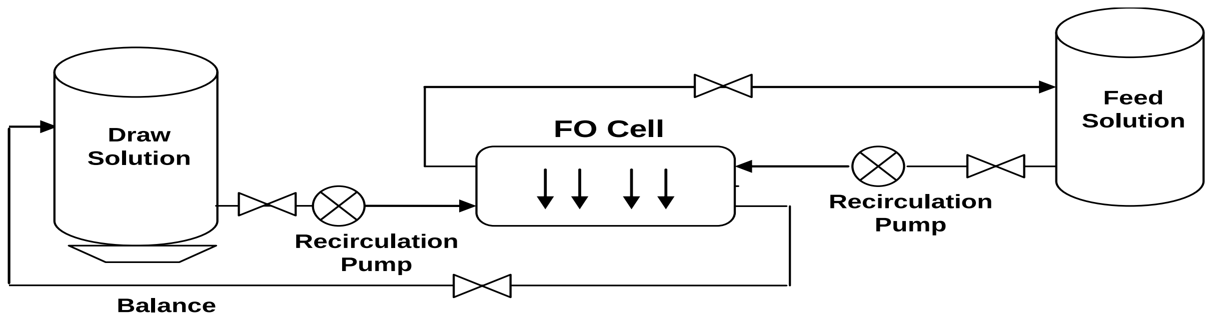

Fig. 1: Closed-loop bench-scale forward osmosis experimental setup

2.2. Materials

2.2.1. Chemicals

Sodium chloride NaCl was from Alpha chemika with minimum assay 99.9 %, and Ammonium bi-carbonate was from Nice laboratory reagent with minimum assay 98.5%.

2.2.2. Membranes

FO thin film woven membrane from Hydration Technology Innovations Company (HTI) was used, this membranes made of cellulose triacetate (CTA) embedded about a polyester mesh. This type of membrane has a thickness of around or less than 50μm, moreover it is relatively smooth and hydrophilic [9]. The HTI membranes have been used in a number of studies, and are currently viewed as the best available membranes for FO applications [10], [11]. In this study, the membrane active layer facing feed was adopted in order to avoid aggravated fouling due to pore-clogging in the support layer if the reverse membrane orientation were to be adopted [12]. Virgin membrane coupons were cut to size and stored in distilled water over night prior to use in each experiment.

2.2.3. Feed and draw solutions

In this study we examined the effect of DS concentrations on the water flux of the FO system using the water of the El-Salam canal as the FS. The DS was prepared using different concentration of NaCl (12, 10, 8, 6 g/l), these concentrations were selected to be comparable to the ground water in Sinai, where the proposed integrated system will be applied. Based on the results obtained from our previous study [13], no detectable heavy metals contamination was found in the canal water, organic pollution is the major notable contamination that found. Accordingly, we take chemical oxygen demand test (COD) as a measure for organic pollutants.

2.3. Measurement of water flux, salt rejection and reverse solute flux

The data collected was used to calculate water flux, reverse draw solute flux and salt rejection. Owing to the initial draw solute concentration in the feed is zero, a species mass balance yields:

$$J_w = \frac{C_F V_{F0} - J_S A_m t}{C_F A_m t}$$

Where: J_w is the measured water flux, C_F is the draw solute concentration in the feed, V_{F0} is the initial volume of feed solution, Am is the membrane area, J_s is the reverse salt flux and t is time.

Based on the amount of fresh water permeating through the membrane from the feed to the draw solution and the amount of salt detected in the draw solution, the salt rejection (r) was determined using equation:

$$R= [1- C_p/ C_F] \times 100\ \%$$

Where C_p is salt concentration of the draw solution (permeate side) for samples taken at any particular sampling time, and C_F is the initial salt concentration of the feed solution.

The reverse salt flux of draw salt in FO mode was determined using mass balance calculation:

$$J_s = \frac{C_t V_t - C_0 V_0}{At}$$

Where C_0 and C_t are the concentration of the draw solute in the feed at time 0 and t, respectively; V_0 and V_t are the volume of the feed at time 0 and t, respectively; A is the membrane area and t is the operating time of the FO experiment.

2.4. Analysis and measurements

Samples were collected throughout the course of each experiment. For all experiments (synthetic or real) waste water, 50 mL samples were collected for analysis from the FS and DS. Analysis of organics was determined as COD. TDS for each experiment was determined according to stander method (APHA, AWWA and WEF 2005).

2.5. FO membrane morphology

The morphology of FO membranes (virgin and used membranes) was investigated by Scanning Electron Microscope (SEM). The membranes were cleaned from glycerol by washing with distilled water, drying at room temperature, fracture in liquid nitrogen and coating gold. After that these membrane samples were investigated in JSM 6400-F field emission scanning electron microscope (Jeol, Japan) at an acceleration voltage of 30 KV.

3. Results and Discussions

3.1. Effect of DS concentrations

Fig. 2 illustrates the water flux versus permeation time for the FO tests with canal water and DS TDS ranged from 6000 to 12000 mg/l. It is clear that, the water flux is markedly influenced by the osmotic driving force which generated from the difference in salinity between FS and DS; in the best case here the salinity difference is about 10000 mg/l at DS of 12000 mg/l. This gives overall water flux 3.3 l/m^2 hr. By decreasing DS concentration the overall flux decreased gradually to 2.6, 2.1 and 1.2 at 10000, 8000 and 6000 mg/l respectively. Fig. 3 demonstrates the effect of DS concentration on reverse salt flux, salt rejection, while Fig. 4 represents the effect on FS COD and COD rejection. Depending on low water flux values, reveres salt flux was found to be very low and it increased slightly by increasing of DS concentration from 6000 to 12000 mg/l, where it increased from 0.06 to 1.2 mol./m^2h, respectively. While salt rejection remained almost constant around 98.7%. With respect to FS COD, a slight decrease from 75 mg/l to about 60 mg/l in all DS concentration was observed, and no COD was detected in DS (100 % rejection). This can be attributed to absorption on membrane surface which was improved by presence of organic fouling on the membrane surface (see next section).

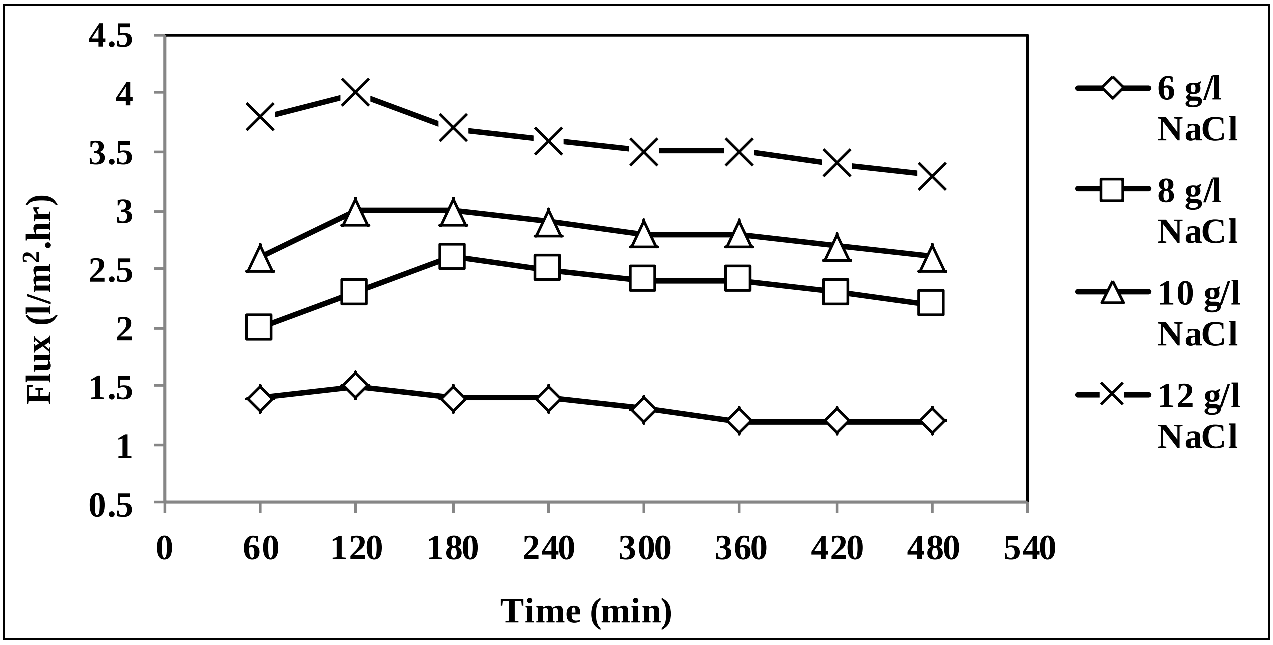

Fig. 2: Flux versus time for FO at different draw solution concentrations

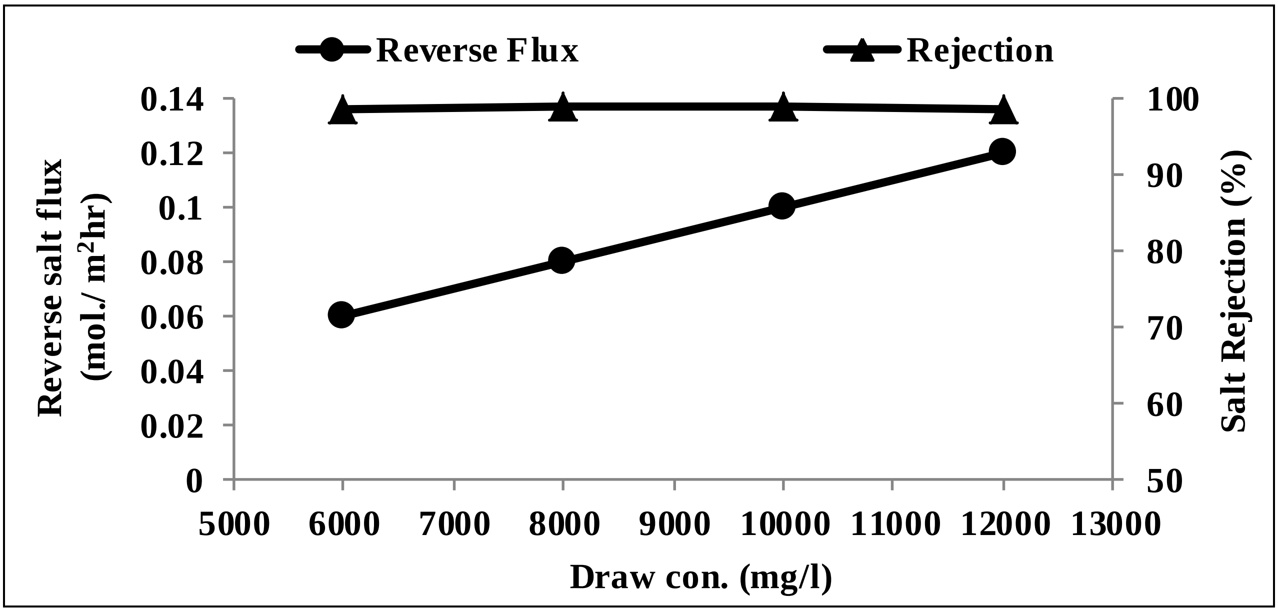

Fig. 3: Effect of draw solution concentration on reverse salt flux and salt rejection for FO operation

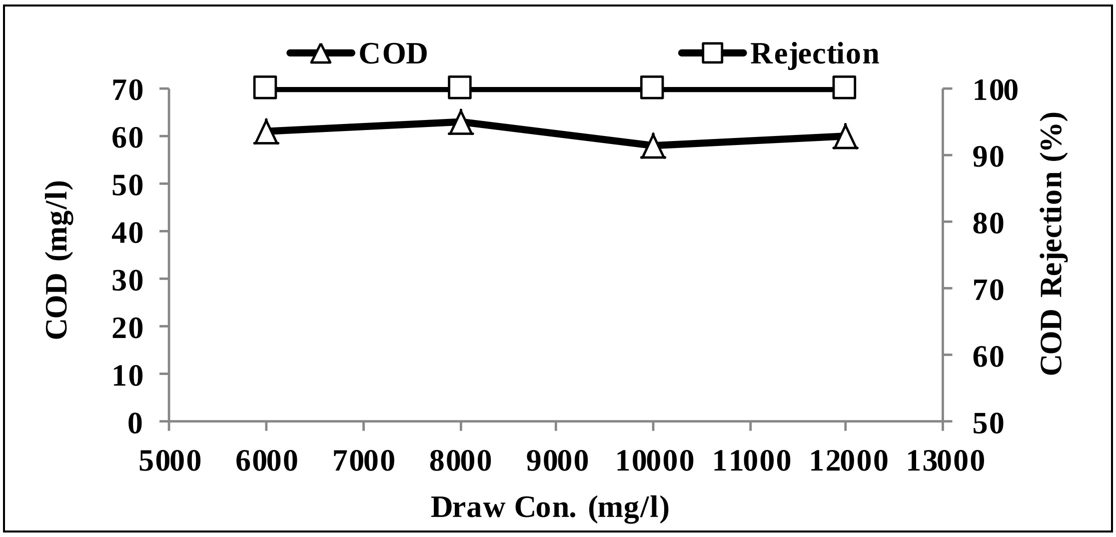

Fig. 4: Effect of draw solution concentration on feed solution COD and COD rejection after 180 minuts FO operation

3.2. Effect of Ammonium Bicarbonate

It is worth noticing that the above results are weak and not promising to be economically applied. So, we studied the improvement of the FO performance by adding draw solute to the DS. Various draw solutes may be used; to make the FO process economically viable. The draw solute must have certain characteristics; it must have a high solubility, a low molecular weight, an easy removal mechanism and a low toxicity [14]. Using a DS of two highly soluble gases ammonia (NH_3) and carbon dioxide (CO_2) satisfies the ideal draw solution criteria [15]. The DS is made by dissolving ammonium bicarbonate salt (NH_4HCO_3) in water. The high solubility in conjunction with a relatively low molecular weight of the salt leads to high osmotic efficiency. Upon moderate heating (near 60 ℃), ammonium bicarbonate can be decomposed into ammonia and carbon dioxide gases. The gases can then be removed from solution by low-temperature distillation using relatively low energy [15].We studied here the improvement of the FO performance with El-Salam canal water by adding ammonium bicarbonate to water wells to increase the osmotic pressure of DS.

Fig. 5 shows the effect of NH_4HCO_3 mixing with DS on water flux versus permeation time. The TDS of DS was 10 g/l, while NH_4HCO_3 concentrations were 5, 10 and 20 g/l. As expected, the overall flux was increased from 2.6 l/m^{2}hr to 3.5, 4.6 and 5.3 l/m^{2}hr at 5, 10 and 20 g/l NH_4HCO_3 respectively. In addition, by increasing the flux, reverse salt flux was increased up to 0.19 mol./m^{2}hr at 20 g/l NH_4HCO_3, and salt rejection was slightly decrease to 97.5% (figure 6). By comparing the flux decline by time with and without NH_4HCO_3, it was found that it is relatively stable and does not reduced significantly.

This is in good agreement with Zhao et al. 2012; which demonstrated that no severe dilutive internal concentration polarization (ICP) occurs in FO process during brackish water desalination [16]; they also conduct comparison with RO flux decline. They found that when the RO membrane is used to desalinate the brackish water, the flux decline is more severe than that of desalting the diluted draw solution after 200-min permeation. This is mainly caused by membrane fouling. At the beginning, the water fluxes in desalting brackish water and the diluted draw solution are similar because less membrane fouling occurs. With the increase of permeation time, the flux decline of desalting brackish water is becoming more pronounced than that of desalting the diluted draw solution because of the foulants in the brackish water while no foulants are present in the diluted draw solution. Furthermore, the applied higher hydraulic pressure in desalting brackish water may also aggravate the flux decline caused by membrane fouling. Accordingly, they concluded that hybrid FO process has many advantages over the stand-alone RO process in brackish water desalination, such as lower hydraulic pressure and less flux decline caused by membrane fouling.

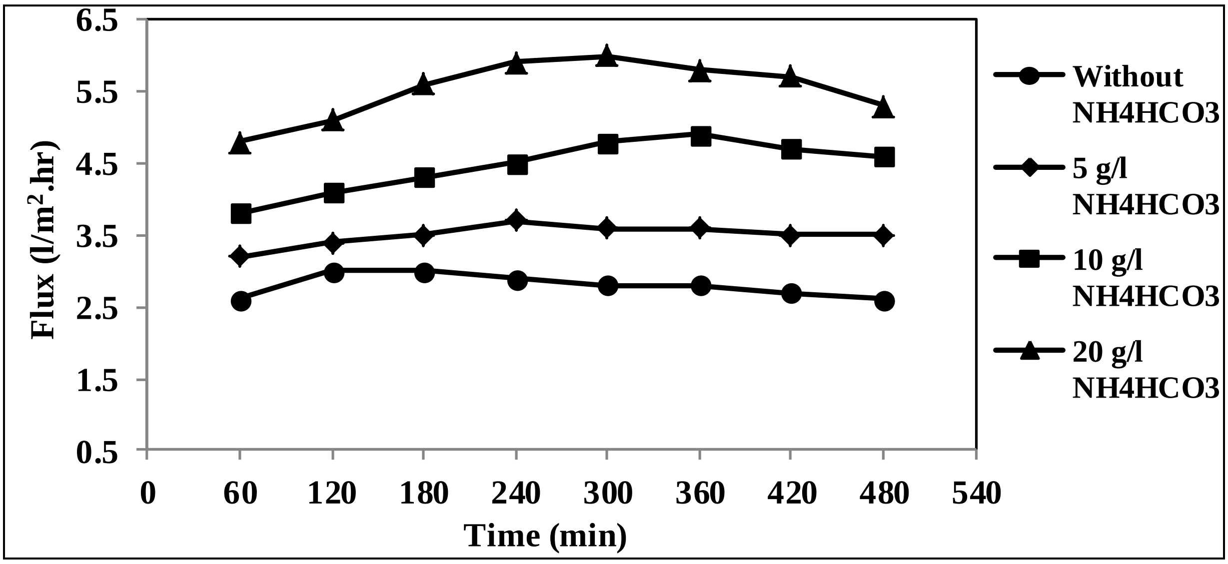

Fig. 5: Flux vs time for FO operation by draw solution containing 10 g/l NaCl and different concentrations of ammonium bicarbonate.

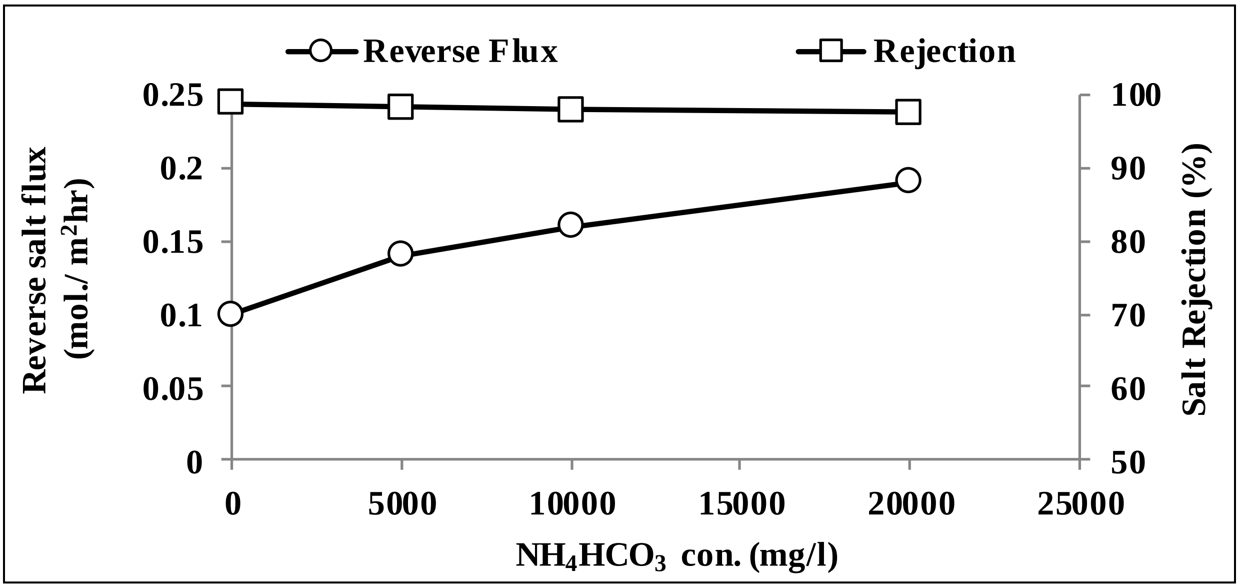

Fig. 6: Effect of ammonium bicarbonates addition on 10000 mg/l NaCl draw solution on reverse salt flux and salt rejection.

3.3. FO membrane morphology

Morphology of virgin and used woven membranes was studied to demonstrate the effect of FS type on the membrane. Fig. 7. (a) and Fig.7. (b) shows the SEM morphology of virgin and used FO membrane, where (a) represent the active layer of the virgin FO membrane which facing feed solution, and (b) implies FO membrane that used in El-Salam canal water. It is obvious that the used FO membrane have some organic fouling, which beside the low osmotic driving force used in these experiments, it may be reduced the water permeation flux. In addition, membrane pore structure and porosity distribution became larger than the virgin one. This can be attributed to the increasing of membrane wetting by the increasing of hydrophlicity which leads to the increase of membrane pore structure and porosity distribution [17], [18].

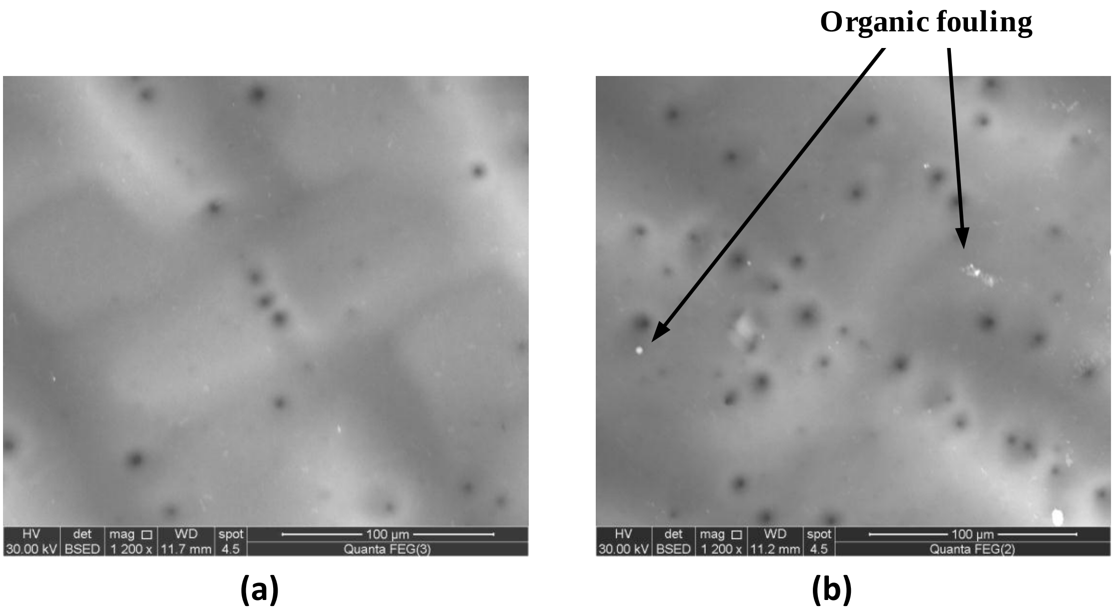

Fig. 7: Morphology of active layer for virgin (a) and used (b) woven FO membrane.

4. Conclusion and Recommendations

In this work, the performance of the forward osmosis (FO) was studied by using El-Salam canal water as feed solution against different concentrations of the DS represented the ground water that excite along the canal. It was found that the results are weak and not promising to be economically applied. So, we studied the improvement of the FO performance by adding draw solute (NH_4HCO_3) to the DS. The overall flux was increased from 2.6 l/m^{2}hr at 0 NH_4HCO_3 (10000 g/l DS) to 3.5, 4.6 and 5.3 l/m^{2}hr at 5, 10 and 20 g/l NH_4HCO_3 respectively. Finally, it can be concluded that utilization of effective draw solutes can markedly improve the process performance. Further emphasis on the development of effective draw solutes and investigation of the performance of combined forward osmosis /reverse osmosis desalination hybrid system are recommended to study the membrane fouling and overall water flux of the system.

5. References

[1] http://www.aucegypt.edu/newsatauc/Pages/oldstory.aspx?eid=1089.

[2] L.F. Greenlee, D.F. Lawler, B.D. Freeman, B. Marrot, P. Moulin, Reverse osmosis desalination: water sources, technology, and today’s challenges, Water Res. 43 (2009) 2317–2348.

[3] Committee on Advancing Desalination Technology of the National Research Council (U.S.), Desalination: A National Perspective, National Academies Press, Washington, DC, 2008.

[4] R. Semiat, Energy issues in desalination processes, Environ. Sci. Technol. 42 (2008) 8193–8201.

[5] L.A. Hoover, W.A. Phillip, A. Tiraferri, N.Y. Yip, M. Elimelech, Forward with osmosis: emerging applications for greater sustainability, Environ. Sci. Technol. (2011).

[6] S. Sourirajan, Reverse osmosis, Academic Press, Inc New York, NY, 1970

[7] APRP-Water Policy Activity Contract PCE-I-00-96-00002-00, Task Order 22, " Survey of Nile system pollution sources", Report No. 64, September 2002.

[8] Hafez A., Khedr M., Gadallah H., El-Khatib K. &El manharawy S., 'El-Salam canal project, Sinai II. Chemical water quality investigations', Desalination 227 (2008) 274–285.

[9] A. Akbari, S. Desclaux, J.C. Rouch, J.C. Remigy, Application of nanofiltration Hollow fibre membranes, developed by photo grafting, to treatment of anionic dye solutions, Journal of Membrane Science 297 (2007) 243–252.

[10] C. Jarusutthirak, G. Amy, J.-P.Croué, Fouling characteristics of wastewater effluent organic matter (EfOM) isolates on NF and UF membranes, Desalination 145 (2002) 247–255.

[11] Y. Wang, F. Wicaksana, C.Y. Tang, A.G. Fane, Direct microscopic observation of forward osmosis membrane fouling, Environmental Science & Technology 44 (2010) 7102–7109.

[12] W.C.L. Lay, T.H. Chong, C. Tang, A.G. Fane, J. Zhang, Y. Liu, Fouling propensity of forward osmosis: investigation of the slower flux decline phenomenon, Water Science and Technology 61 (2010) 927–936.

[13] Process Design and Optimization of hybrid forward and reverse osmosis process for water desalination, STDF project, 1st progress report, October 2012.

[14] J. L. McCutcheon, R. L. McGinnis, M. Elimelech, "The Ammonia-Carbon Dioxide Forward Osmosis Desalination Process", *Water Conditioning & Purification,* October, 2006.

[15] J. R. McCutcheon, R. L. McGinnis, M. Elimelech, "A novel ammonia–carbon dioxide forward(direct)osmosis desalination process", Desalination 174 (2005)1–11.

[16] S. Zhao, L. Zou, D. Mulcahy, 'Brackish water desalination by a hybrid forward osmosis–nanofiltration system using divalent draw solute", Desalination 284 (2012) 175–181.

[17] McCutcheon, J.R.; Elimelech, M. Influence of membrane support layer hydrophobicity on water flux in osmotically driven membrane processes. J. Membr. Sci. 2008, 318, 458–466.

[18] S. Lee, C. Boo, M. Elimelech, S. Hong, Comparison of fouling behavior in forward osmosis (FO) and reverse osmosis (RO), Journal of Membrane Science 365 (2010) 34–39.