Effect of salinity and temperature on treatment of concentrated wastewater from RO by FO-MD

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Abstract. In this study the appropriate temperature of the membrane distillation (MD) hot side (the permeation flux of MD was controlled by adjusting the hot side temperature) was selected according to the water flux of FO process so that the water transfer rate on both sides of FO and MD was consistent and the FO-MD process could be stable operation. When the salt concentration of feed solution was 30, 55, 80 and 100 g/L, the desalination rates changed little, which were 99.1%, 98.4%, 98.9% and 98.7%, respectively. The removal rate of COD was 93.8%, 94.2%, 91.6% and 92.7% which also changed little like the desalination rates. The removal rate of chromaticity increased with the increase of salinity, which attained 96.6%, 97.0%, 97.2% and 97.9%, respectively. This study proved that salinity of the feed solution affected little on the removal rate of contaminants but great on the water flux, with the increase of salinity from 30 to 100 g/L, the water flux was 6.05, 4.81, 4.33 and 3.87 LMH with the appropriate temperature (67.5±0.5, 64.5±0.5, 62.5±0.5 and 60.5±0.5 °C) of MD hot side. In a word, FO-MD was first used to treat the high salinity RO water with over 30 g/L total dissolved solids (TDS), FO-MD was a promising new process for high salinity wastewater treatment, and the hybrid system can solve the problem of lower draw solution concentration, and the high-quality production water will be obtained directly by this hybrid system with low membrane fouling tendency.

1. Introduction

With the development of membrane technology, reverse osmosis technology (RO) is being widely used in the treatment of various types of wastewater. However, high salinity RO concentrated wastewater has become a major problem in the process of wastewater treatment.

In recent years, as a newly developed membrane technology, forward osmosis (FO) has been used for desalination, dewatering of high nutrient sludge, textile wastewater treatment and so on in many studies[1–4]. And significant differences between FO and other pressure-driven membrane technology are that FO need low pressure and even no pressure so its membrane fouling is lower, besides, high fouling reversibility and high rejection rate for ammonium, phosphate and heavy metals have been proved by other studies[5–9]. According to the literature[10] that as it is less sensitive to membrane fouling and feed salinity, membrane distillation (MD) has a greater advantage in the treatment of high salinity wastewater compared with other thermal processes while the concentration of MD is excellent (theoretically, 100%) and its operation is simple. The literatures[11,12] have shown the potential of desalination of FO-MD combined process, which can effectively concentrate high nutrient sludge, remove arsenic in water, treat dye wastewater, treat human urine and so on.
In this study, MD was combined after FO process so that the problem of lower draw solution concentration can be solved. Effect of temperature and salinity was investigated on the performance of the combined FO-MD process.

2. Materials and methods

2.1. Materials
Thin film composite (TFC) membrane from Hydration Technology Innovations (Albany, OR) was used for FO process. A hydrophobic microporous PTFE/PVDF composite membrane with a pore size of 0.45 microns from Shanghai Ming Lie Chemical Technology Co., Ltd (Shanghai, China) was used for the MD process. The FO module and the MD module were made of acrylic sheet with the effective area of 21 cm² (3 cm×7 cm) and 5 mm deep channel.

The wastewater was the high salinity water from RO (30 g/L TDS, 180 mg/L COD, 800 chromaticity as A=1.411) which collected from a waste incineration plant in Nanjing. The draw was NaCl solution.

2.2. Methods
Three variable speed micro gear pumps (Longer Pump, WT3000, Baoding, China) were used to circulate the feed (FS), draw (DS) and permeate solutions (PS). High-precision low-temperature thermostat bath (Yiheng, HWS-24, Shanghai, China) and electro-thermal constant temperature water bath (Xinzhi, GDH-0506, Ningbo, China) were used to control the temperature and two sides of FO module and the permeate solution was maintained at 15±0.5 °C and the feed temperature of MD was dependent on the water flux of FO.

In the FO process, 0.5 L RO concentrated water with different salt concentration was used as feed solution (the flow rate 0.87 L/min) and 0.5 L 4.82 M NaCl solution was used as draw solution (the flow rate 0.31 L/min). In the study, the active layer of TFC membrane against feed solution (AL-FS mode). The operating time of FO process is 2 h.

Different salt concentration of high salinity wastewater (55 g/L, 80 g/L, 100 g/L) was prepared based on the RO concentrated water as shown as table 1 from the incineration plant by adding NaCl. Then optimal FO-MD was used to treated these high salinity wastewaters further to obtain purified water and DI water was pre-permeated to improve cooling efficiency at the side of the permeate. The FO-MD schematic diagram was shown in Figure 1.

The water flux $J_W$ (L·m⁻²·h⁻¹, abbreviated as LMH) can be calculated by equation (1).

$$J_W = \frac{V}{S_m t}$$

where $\Delta V$(L) is the permeation water volume change at operating time $\Delta t$ (h) and $S_m$ is the effective membrane surface area (m²).

The salt reverse flux $J_S$ (g·m⁻²·h⁻¹, abbreviated as gMH) was determined by equation (2).

$$J_S = \frac{C_f V_f - C_{f0} V_{f0}}{S_m t}$$

where $C_{f0}$ (mg·L⁻¹) and $V_{f0}$ are the solute concentration and the feed solution volume at the beginning, as well as $C_f$ and $V_f$ are the solute concentration and the feed solution volume after time $\Delta t$.

Conductivities of the solutions were recorded by conductivity meter to calculated the TDS, chromaticity was measured by UV-Vis spectrophotometer at 242 nm wavelength and chemical oxygen demand (COD) was determined by dichromate method.
3. Results and discussion

3.1. The appropriate temperature of MD

In this study, to determine the appropriate temperature of MD and ensure the stability and continuity of FO-MD hybrid system, it is necessary to match the water transfer rate in FO process to that in MD process. Figure 2 shows that with the increase of temperature at the MD hot side, the permeate flux of MD was increased (R² is 0.9875), and the salt rejection was higher than 98% no matter how the temperature changes. In Figure 3, under different concentrations of the feed solution and optimal temperatures of MD, the water transfer rate in FO process was close to that in MD process, so 67.5±0.5, 64.5±0.5, 62.5±0.5 and 60.5 ±0.5 °C were selected as the inlet temperature of MD when the salt concentration of FS was 30, 55, 80 and 100 g/L, respectively.

![Figure 1. The FO-MD schematic diagram.](image)

![Figure 2. The permeate flux and the salt rejection in individual MD process with the change of inlet draw solution temperature. The feed: 0.5 L 4.82 M NaCl solution, and the pre-permeation water: 0.2 L DI water. The flow rate for both sides: 0.31 L/min. Experimental duration: 2 h.](image)
3.2. The removal of contaminant

Integrated FO-MD process was used to treat the RO concentrated water with the optimized operation of FO and MD. Shown as Figure 4, the chromaticity can be measured by the absorbance (A) at 242 nm wavelength, because absorbance increases with increasing chromaticity. Therefore, in this study, the absorbance (A) was used to represent the chromaticity of wastewater.

In Figure 5, The removal rate of COD was higher than 90%, which was not sensitive to the changes of salt concentrations in the FS under the optimized operation conditions, while, the absorbance of the produced water decreased with the increasing salt concentration of FS, because the increase of salt concentration has a negative effect on the rejection of macromolecular substances which caused the color of the water in the FO process according to the solution–diffusion mechanism, but, it was worth mentioning that the removal rate of the chromaticity remained over 96% by the FO-MD process and the color of the water was very close to deionized water.

Figure 3. The water transfer rate of FO and MD in FO-MD process. The flow rate of PS was 0.31 L/min as that of the DS. In FO and MD stage 1, 2, 3, 4: The salt concentration of FS 30, 55, 80, 100 g/L, the inlet temperature of MD 67.5±0.5, 64.5±0.5, 62.5±0.5, 60.5±0.5 °C, respectively.

Figure 4. The relationship between A and 1/N. The initial A of the wastewater is 1.411, the A at the dilution end point is 0.011. A: the absorbance. N: the dilution factor.
Figure 5. The removal rate of COD and the absorbance of the produced water when the salt concentration of the FS changed in the FO-MD process.

As shown as Figure 6, the desalination rates of FO-MD process were higher than 98% when the salt concentration changed from 30 g/L to 100 g/L, it meant that the effect of salinity on the desalination rates of FO-MD can be ignored and showed excellent desalination capacity of FO-MD process.

Figure 6. The desalination rate of FO-MD process.

4. Conclusions
In this study, integrated FO-MD process has shown excellent performance on RO concentrated water with the desalination (over 98%), the removal capacity of COD (over 90%) and chromaticity (over 96%). This study demonstrated that in the FO-MD system the salinity of the feed solution had little effect on the removal rate of contaminants, but had a significant effect on the water flux. With the increase of salinity from 30 to 100 g/L, the water flux was 6.05, 4.81, 4.33 and 3.87 LMH with the appropriate temperature (67.5±0.5, 64.5±0.5, 62.5±0.5 and 60.5±0.5 °C) of MD hot side. Wastewater with a salinity higher than 30 g/L was suitable for the combined process and the process can be a potential for the treatment of high salinity wastewater in the future.
Acknowledgment
This work was supported by the National Natural Science Foundation of China [No.21477018], the fundamental research funds for the central universities [No.15D111323] and the Science and Technology Program of Transport Ministry [No. 2010353343290].

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