Influencing Factors of DCMD for Treatment of RO Concentrate Wastewater on Water Reclamation

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Abstract. Direct Contact Membrane Distillation (DCMD) device with PVDF as the core was introduced to treat concentrated Reverse-Osmosis (RO) wastewater on water reclamation. Effects of feed temperature, feed flow rate and permeate flow rate on flux were investigated. Furthermore, variation low of permeate flux and the main water quality during long-term membrane distillation (MD) performance were discussed. It can be concluded from the result that the permeate flux were increased with the feed temperature. When the temperature difference between hot-side and cool-side reached 35℃, the permeate flux was 7.15 kg/(m²•h), and then the growth trend of flux slowed down. The permeate flux were increased with the increase of feed flow rate and permeate flow rate, and the peak reached 8.2 kg/(m²•h) in the whole process. The permeate flux stabilized at 7.1~8.36 kg/(m²•h) during 16 hours long term experiment performance and the permeate water quality were kept steadily.

1. Introduction

The Reverse-Osmosis (RO) is a new type of membrane separation technology developed from 1960s. The RO process was normally used to produce reclaimed water in municipal sewage plant, while concentrated wastewater was generated. Discharge of such concentrated wastewater would contaminate the soil, surface water and sea water, because it contained many of organic and inorganic pollutants. The higher total dissolved solids (TDS) in such RO concentrate wastewater was harmful to the growth of activated sludge if it was discharged directly. It is a hard task for advanced treatment to the RO concentrate wastewater[1]. The commonly employed approaches include enhancing the rate of recovery, comprehensive utilization, evaporation concentration, membrane distillation (MD) and so on[2,3]. The MD is a new membrane separation technology in which the temperature gradient created on membrane surfaces was used as a driving force to treat feed solution[4]. An attractive alternative for the removal of various volatile contaminants is possible with the development of hydrophobic hollow fiber membrane[5-9]. MD can be investigated under relatively low pressure or low temperature with low energy consumption and high productivity which was Compared with conventional separation processes, such as distillation, evaporation and reverse osmosis[10-11]. This paper took the RO concentrated wastewater as the research object, which was collected from one of Beijing reclamation water plant. The objective of the research is to discuss the effect of temperature, feed flow rate and permeate flow rate on permeate flux by direct contact membrane distillation.
2. Materials and methods

2.1. Experimental materials
The PVDF hollow fiber membrane was self-made in the experiments, and the characteristics are shown in Table 1. The membrane module was made by a poly-ester tube and two UPVC T-tubes. The inside / outside diameters of the module were 0.9/1.2 mm and the effective length of the module was 120 mm. The module was equipped with 50 hydrophobic PVDF hollow fiber membranes. The total efficient area of the module was calculated for the internal diameter of hollow fiber membrane.

| Parameter      | Value | \( \text{d_i/d_o} \) (mm) | \( \varepsilon \) | Average pore radius(μm) | \( \delta \) (mm) | LEPw( kPa) |
|----------------|-------|----------------------------|-----------------|--------------------------|-----------------|------------|
|                |       | 0.9/1.2                    | 78%             | 0.26                     | 0.15            | 250        |

a Inside /outside diameter of the capillary membrane; b Porosity; c Membrane thickness. d Liquid entry pressure of water

The experimental feed is RO concentrate wastewater collected from one of Beijing reclamation water plant. The water quality is shown in Table 2 which were analyzed by the water quality monitors respectively.

| Parameter | Value |
|-----------|-------|
| pH        | 7.6-8.1|
| K⁺        | 82.2  |
| Na⁺       | 1010  |
| Ca²⁺      | 400   |
| Mg²⁺      | 56.4  |
| TDS       | 4500  |
| σ         | 6670  |

2.2. Experimental setup
The experimental setup for the removal of RO concentrate wastewater is schematically shown in Fig. 1. The feed, RO concentration wastewater, was pumped in the membrane lumen side while the condensate solution was fed into the shell side of the membrane module in co-current flow. The permeate flux was measured by the overflow volume of the permeate reservoir.

2.3. Experimental methods
In order to discuss the MD interfering factor, the temperatures and flow rates of permeate were kept at 20°C and 0.2m/s respectively while the feed flow rate were implemented at 0.4m/s, 0.6m/s, 0.8m/s, 1.0m/s successively, and the feed temperatures were adjusted at 40°C, 45°C, 50°C, 55°C, 60°C, 65°C, 70°C respectively. The permeate flux were measured by the overflow volume of the permeate reservoir and the effect were studied by controlling the permeate flow rates.

2.4. Long-term membrane performance for RO concentrate wastewater removal
In order to evaluate the RO concentrate wastewater removal efficiency and the stability of PVDF membrane, a continuous PVDF membrane performance was conducted. The permeate concentration of TDS, conductivity and permeate flux were measured as a function of elapsed time.

3. Results and discussion

3.1. Influence of different feed temperature on permeate flux
The influence of feed temperature on permeate flux is shown in Fig. 2. It can be seen from Fig. 2, the permeate flux increased with the increase of feed temperature. When the permeate flow rate was controlled at 0.2 m/s and feed temperature was adjusted at 40°C, the permeate flux reached 3.2 kg/m²·h. The permeate flux went steadily up to 8.2 kg/m²·h when the permeate flow rate was controlled at 1.0m/s and feed temperature was raised at 70°C, respectively. The permeate flux is of strong upward tendency with the increasing of feed temperature bellow 55°C and then the tendency slows down. The reason is that the feed vapor pressure will rise rapidly and the pressure gradient created on membrane surfaces as a driving force will increase simultaneously with the increasing of feed temperature.

3.2. Influence of different feed flow rate on permeate flux
The influence of feed flow rate on permeate flux is shown in Fig.3. It can be seen from Fig.3, the permeate flux increased with the increase of feed flow rate at same temperature. When the permeate flow rate and feed flow rate was both controlled at 0.2 m/s and feed temperature was adjusted at 40°C, the permeate flux reached 3.18 kg/m²·h. The permeate flux stayed at 3.7 kg/m²·h when the feed flow rate was controlled to 1.0m/s and feed temperature was kept at 40°C. However, the permeate flux got up to 8.2 kg/m²·h when the feed temperature was adjusted at 70°C and the feed flow rate was kept at 1.0 m/s. To analyze the reason, it is because both the heat and Mass transfer coefficient will rise rapidly and the concentration boundary layer created on membrane surfaces will decrease simultaneously with the increasing of feed flow rate[12-15].
3.3. Influence of different condensate flow rate on permeate flux

The influence of permeate flow rate on permeate flux is shown in Fig. 4. It can be seen from Fig. 4 that the permeate flux increased with the increase of permeate flow rate at same temperature, but the upward tendency is not sharp. The permeate flux stayed only at 3.15 kg/m$^2 \cdot$ h when the permeate temperature, the permeate and feed flow rate was controlled at 40°C, 0.1 m/s, 0.6 m/s respectively. However, the permeate flux rose to 8.0 kg/m$^2 \cdot$ h when the feed temperature was adjusted at 70°C and the permeate flow rate was kept at 0.6 m/s.

![Fig. 4. The influence of permeate flow rate on permeate flux.](image)

3.4. Performance of long-term membrane process

The long-term membrane process for RO concentrate wastewater removal was conducted to test the stability of membrane. Considering the higher concentration of TDS and conductivity in feed, both of them were tested for permeate. The result of performance of continuous membrane distillation process is as seen in Fig. 5. It can be seen from Fig. 5 that the permeate flux was kept steadily at 8.0~8.36 kg/(m$^2 \cdot$ h). The permeate conductivity was kept at 4.95~5.3 μS/cm in 12 hours. A sharp increase of permeate TDS and conductivity was observed after 12 hours of the process.

![Fig.5 Performance of continuous membrane distillation process](image)

4. Conclusion

In conclusion, the direct contact membrane distillation process with hydrophobic hollow fibre PVDF provided an effective method for the removal of RO concentrate wastewater. The permeate flux increased with the increasing of feed temperature and flow rate. The maximal permeate flux got up to 8.36 kg/(m$^2 \cdot$ h) when the feed temperature was adjusted at 70°C and the feed flow rate was kept at 1.0 m/s. The tendency slows down after the temperature above 55°C. The permeate flux increased with the increasing of permeate flow rate at same temperature, but the upward tendency is not sharp. The permeate flux was kept steadily at 8.0~8.2 kg/(m$^2 \cdot$ h) and the permeate conductivity was kept at 4.95~5.3 μS/cm in 12 hours long-term experiment which showed the membrane distillation process is an effective method for RO concentrate wastewater treatment.
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