Hybrid Membrane Processes for Water Reuse

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Background

- Dual barrier approach is applicable for potable reuse
- Low energy, high-quality forward osmosis (FO) water recovery process
- Waste heat and energy from anaerobic biological process used for direct contact membrane distillation (DCMD)
- Low energy nutrient (N & P) recovery for beneficial reuse

Results

The results of carbon and nitrogen rejection of the FO-DCMD system are shown in Table 1. The FO-DCMD system rejection of TOC and TN are 98%. Although the rejection of nitrogen species of the benchscale FO could be higher, DCMD effectively rejects the nitrogen species. Although TOC rejection of DCMD is only 68%, FO effectively removes TOC attributing to an effective rejection by the system.

The results presented below involves two approaches in maintaining the system at steady state during 12hr experiments. The first was to maintain the draw solution constant with the self-adjusting heater PID. In Figures 1 and 2, the DCMD feed was bounded at 50°C and 1°C. While operating within these bounds, the heater is capable of maintaining a relatively constant draw solution concentration. As the draw solution temperature increases, the water flux of FO and DCMD increases. The DCMD process is influenced primarily by temperature variations in the draw solution. As the draw solution temperature is decreased the water flux through DCMD decreases and the FO draw solution flux slightly more is concentrated. However, the increase in draw solution concentration is low enough so that the pressure gradient across the FO membrane remains substantially unchanged.

The specific reverse salt flux can provide an estimation of the draw solution replenishment requirements. The specific reverse salt flux is the amount of NaCl that must be supplied to the system to maintain a constant draw solution concentration. For example, a NaCl draw solution at a temperature of 50°C will lead to a loss of 0.5 g of NaCl per liter of solution (Figure 2). The low specific reverse salt flux occurs when the draw solution temperature is at the upper bound (50°C). Conversely, the high specific reverse salt flux occurs when the draw solution temperature is at the lower temperature bound (30°C). This result indicates that the specific reverse salt flux is minimized as the temperature gradient across the FO membrane is increased.

Materials and Methods

Constant heat was used instead of a PID control as the next approach in stabilizing the system (Figure 3 and 4). The constant delivery of heat was measured as a percentage of heater operation (% on). The distillate temperature was maintained at 20°C using a heat exchanger to transfer heat away from the distillate side. A proportional control valve was utilized to regulate the flow of water through the heat exchanger to assure the distillate temperature is maintained at 20°C. This approach in heating is more realistic for scaleup and industrial processes rather than varying temperature as in Figure 1 and 2). Results from steady increments in heater operation provide a range of DCMD water flux with varying feed side temperatures (Figure 3). The relatively steady operating temperature lends itself to constant FO and DCMD water flux (Figure 4).

Conclusions

The bench-scale FO-DCMD system rejection of T (98%) and TOC is 98% (Table 1). Water fluxes in DCMD and FO are maximized as the temperature gradient is increased and minimized with decreased temperatures (Figure 1). The reverse salt flux is decreased as the temperature gradient across the FO membrane is increased (Figure 2).

The heater can maintain a constant draw solution concentration while operating under appropriate temperature bounds. However, constant heating may provide a more efficient and realistic approach for upscaling (Figure 3 and 4).

Acknowledgements

The authors would like to thank the Shellefeller Research Foundation for funding the project, the Environmental Protection Agency for funding, Jairo Luque Villanueva, and the HSE Faculty and staff for their continued support. Special thanks to EROS Student Dmitriy Fedorov and ERE Alumna Laina Winkle for assisting in the research.

References


Objectives

The purpose of this study is to investigate a hybrid forward osmosis-direct contact membrane distillation (FO-DCMD) bench scale system that was designed and constructed at HSE. Experiments were conducted to determine water fluxes and specific reverse salt flux. The water fluxes were used to evaluate the rejection of carbon and nutrients for the purposes of energy utilization and nutrient recovery.

Materials and Methods

- FO-DCMD bench scale system
- In-line heater
- Proportional control valve
- Forward osmosis module
- Direct contact membrane distillation module
- Heat exchanger
- Tank
- Flow meters
- Pumps
- Conductivity probes

\[ \text{Water Flux} = \frac{J_w}{A_m - 1} \text{L} \cdot \text{m}^{-2} \cdot \text{h}^{-1} \]

\[ \text{Reverse Salt Flux} = \frac{J_s}{A_F} \text{g} \cdot \text{m}^{-2} \cdot \text{h}^{-1} \]

\[ \text{Rejection} = \frac{C_p - C_f}{C_p} \times 100\% \]

Where \( C_p \) is the contaminant concentration of the water that permeates through the membrane; \( C_f \) is the concentration of the feed solution. For the FO process; \( C_p \) is the contaminant concentration in the feed tank while for the DCMD process, \( C_p \) is the contaminant concentration in the draw solution tank. \( C_f \) is determined experimentally by finding the mass of the contaminant (mg) and the volume of water (L) that permeates through each membrane process. \( A_F \) is the membrane area and \( t \) is the duration of the experiment. The water flux \( J_w \) for the FO and DCMD processes are determined experimentally using pressure transducers that detect changes of volume in the distilled water feed tank and distillate tank over time. Lastly, the reverse specific salt flux is the ratio of the reverse salt flux to the water flux \( J_w/A_m \).