Numerical Modelling of the Effect of Fouling on the Permeate Flux in Membranes

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Abstract

Porous membranes have been widely used for brackish water desalination. However, fouling extensively reduces permeate flux in reverse osmosis (RO) and/or nanofiltration (NF) membranes. We attempted to model salt concentration profile and find the effect of fouling on the permeate water flux. Parabolic (or diffusion) partial differential equation and forward finite difference method (explicit) were used in the numerical analysis. It was found that salt accumulation occurs at the membrane feed-side surface and there was a noticeable decrease in water flux as fouling increased.

Assumptions

Selected membranes for the study (brackish water treatment) were RO and/or NF with the following assumptions as in Table 1.

Table 1. Study parameters and their selected values [1–3]

Parameter (Symbol)	Value	Unit
Rejection (R); for RO and NF*	95 and 50, respectively	%
Initial salt concentration (C_0)*	10000	ppm
Fouling concentration (C_f)*	0 ~ 20000	ppm
Water diffusivity (D)	1.3×10^{-6}	cm² s⁻¹
Membrane thickness ($z = L$)	250	μm
Treatment/passing time (t)	25	s

*for brackish water with sodium chloride salts (NaCl) only.

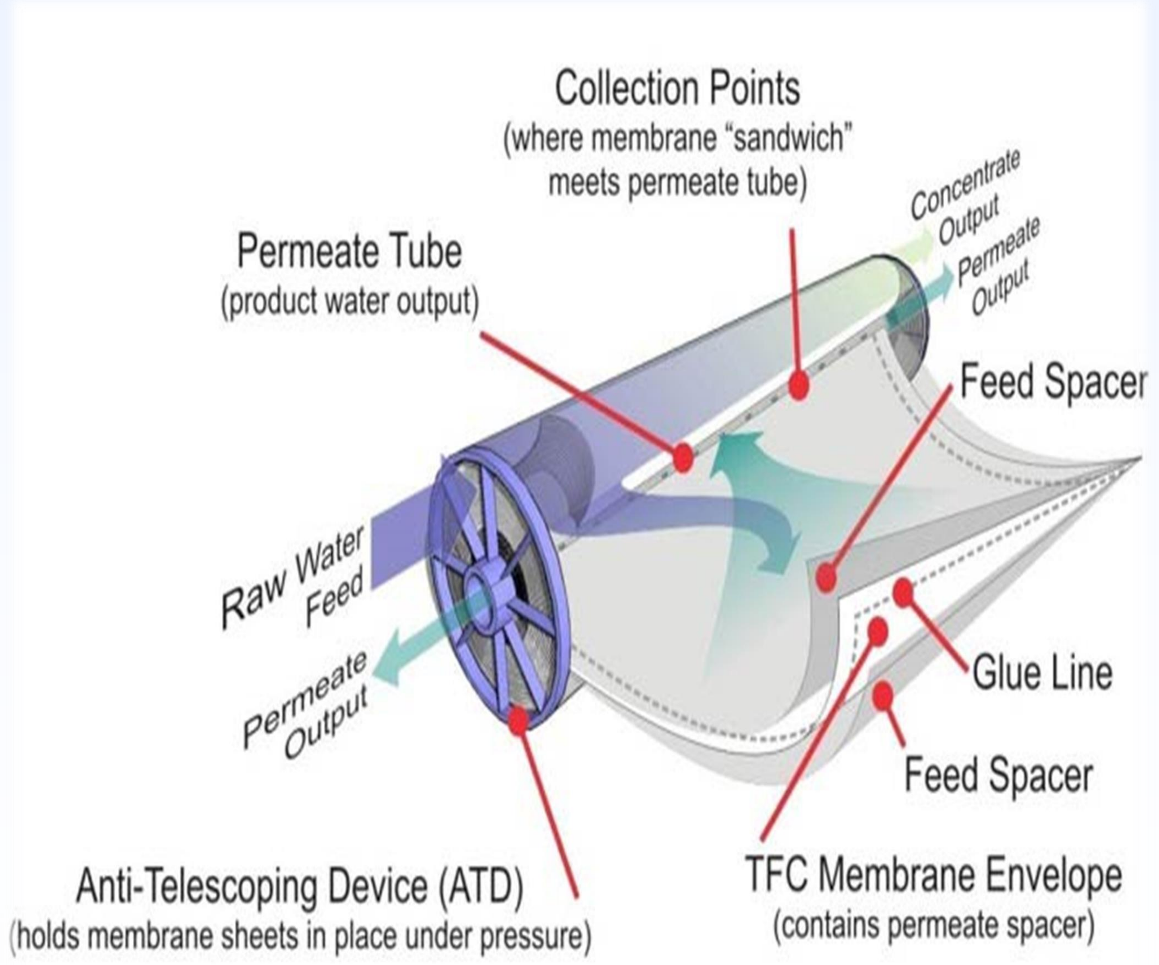

Fig. 1. Spiral-wound RO membrane configuration [4]

Methods and Equations

Parabolic (or diffusion) partial differential equation from Eq. (1) has been used along with applying forward finite difference method (explicit) to get Eq. (2), $\{(i,k) = (z,t)\}$, which is capable of estimating salt concentration profile within the membrane from MATLAB [5,6].

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2} \quad (1)$$

$$C_i^{k+1} = C_i^k + \frac{D\,\Delta t}{(\Delta z)^2}\left(C_{i+1}^k - 2C_i^k + C_{i-1}^k\right) \quad (2)$$

Total water flux across the membrane was determined from Fick's first law [5] from Eq. (3) at the selected fouling concentrations. Initial, fouling and total flux rates were calculated from both Eq. (4) and Eq. (5).

$$J = -D\frac{dC}{dz} = -D\left[\frac{C - C_0}{z - z_0}\right] \quad (3)$$

$$J_0 = -D\left[\frac{C_P - C_0}{L}\right] \; ; \; J_f = -D\left[\frac{C_f - C_0}{L}\right] \quad (4)$$

$$J_T = J_0 - (J_0 - J_f) \quad (5)$$

Where J is the flux rate (g cm^{-2} s^{-1}); subscripts 0, P and f refer to initial, permeate and fouling, respectively, D is water diffusivity into the membrane (cm^2 s^{-1}), C is salt concentration in (g cm^{-3}) and z refers to the spatial position (cm) with respect to membrane thickness, L (considering PA layer only for flux calculations; fouling layer assumed to be as the PA layer; Fig. 2 & Table 2).

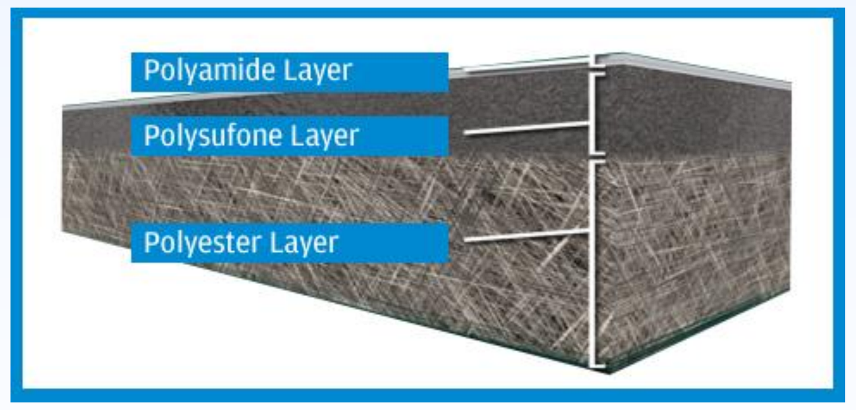

Fig. 2. Membrane layer structure [7]

Table 2. RO/NF Membrane layers and their thickness [3]

Membrane Layer	Selected	Literature
Polyamide (PA)*	62.5 nm	1 ~ 200 nm
Polysulfone (PSF)	40 μm	30 ~ 50 μm
Polyester (PEST)	150 μm	100 ~ 200 μm

*Flux rates were calculated based on the PA layer only; since resistance of other layers were neglected due to the larger pores

Results

Fig. 3 shows fouling effects on salt concentration profile inside the membrane; and Fig. 4 shows fouling effects on water flux rates across the membrane. Higher fouling results in:

- Higher accumulations on the membrane surface which decreases the treatment efficiency
- Lower flux rates due to salt accumulations ($J_T = 0$ at $C_f = C_0$; and backflow at $C_f > C_0$)

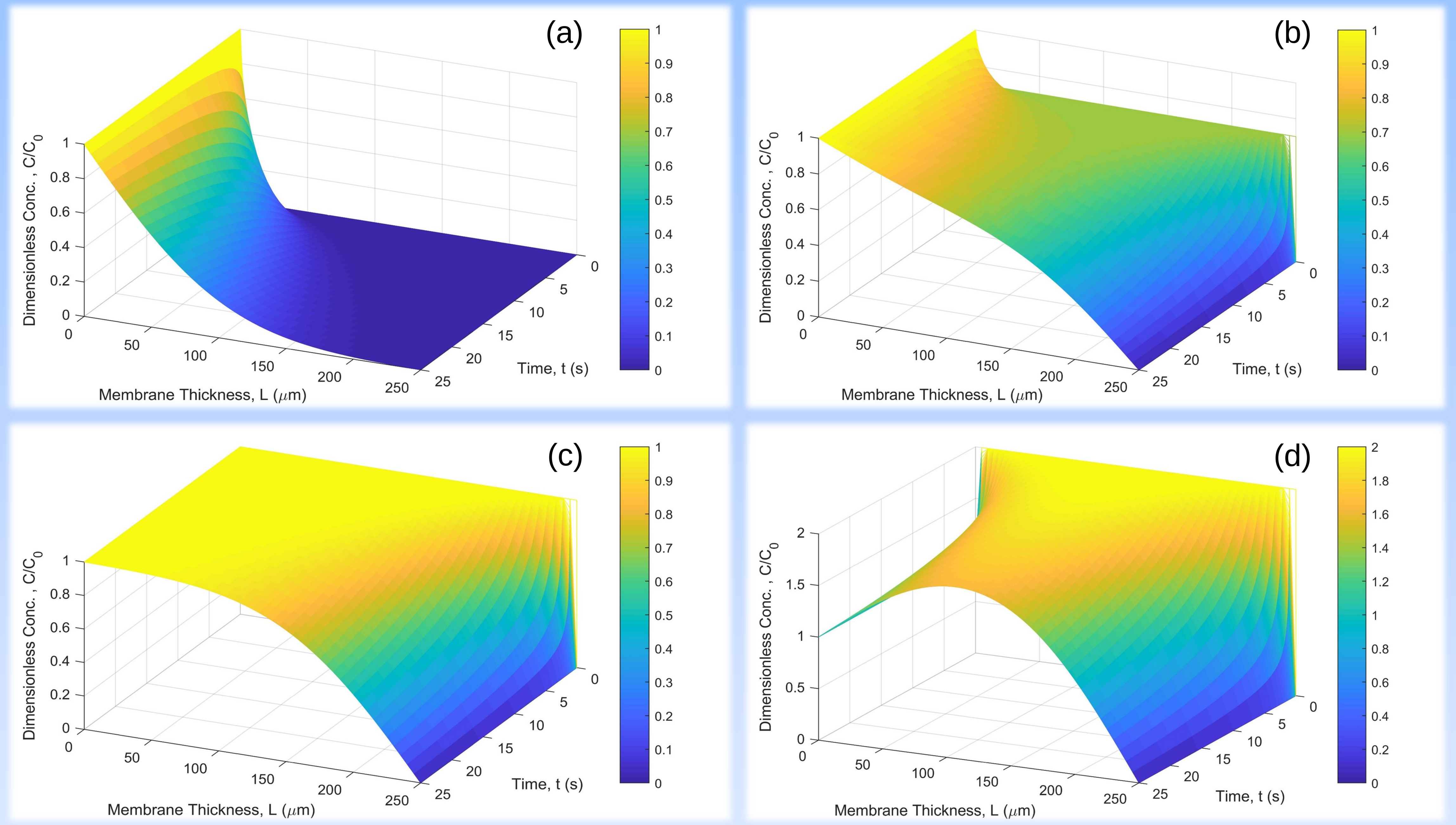

Fig. 3. Salt concentration profile as a function of time and thickness at initial concentration (C_0) of 10000 ppm and different fouling concentrations (C_f) as the following: (a) 0 ppm; (b) 7000 ppm; (c) 10000 ppm and (d) 20000 ppm

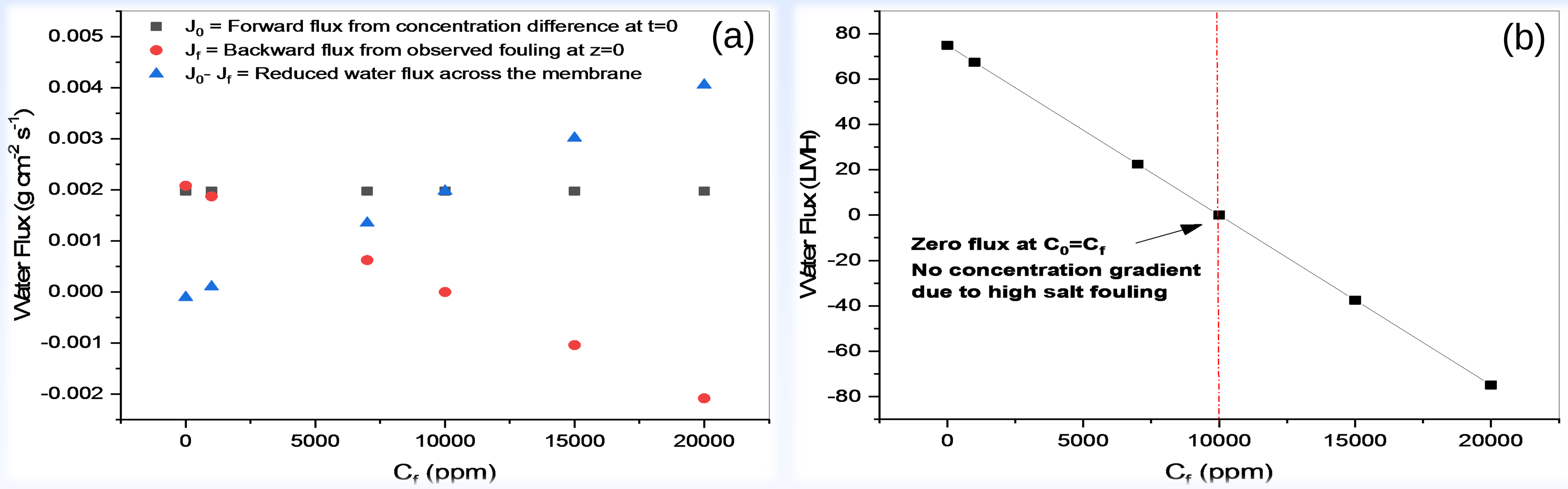

Fig. 4. Observed water flux across the membrane at initial concentration (C_0) of 10000 ppm and at different fouling concentrations (C_f): (a) Forward, backward and reduced fluxes; (b) Total flux $\{J_T = J_0 - (J_0 - J_f)\}$

Conclusion

Numerical analysis concluded that fouling has severe impacts on RO/NF membranes. Fouling refers to higher salt accumulations:

- Decreased treatment efficiency
- Lower flux rates

References

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