Membrane fouling in osmotically driven membrane processes: A review

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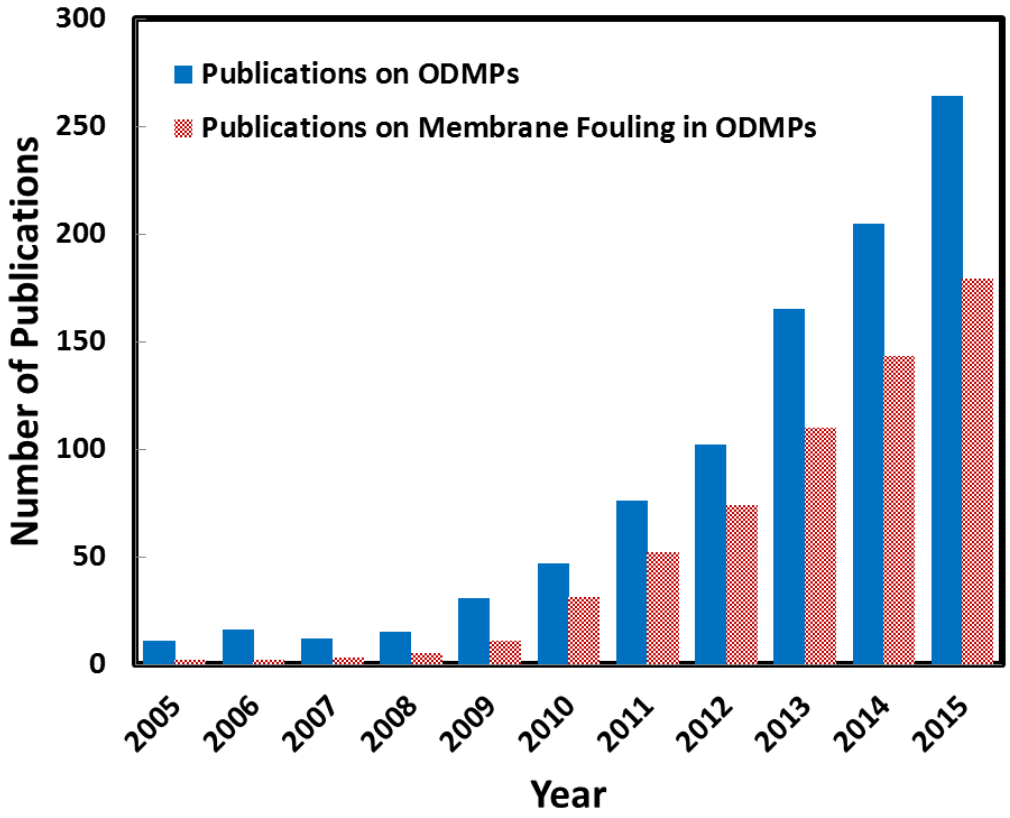
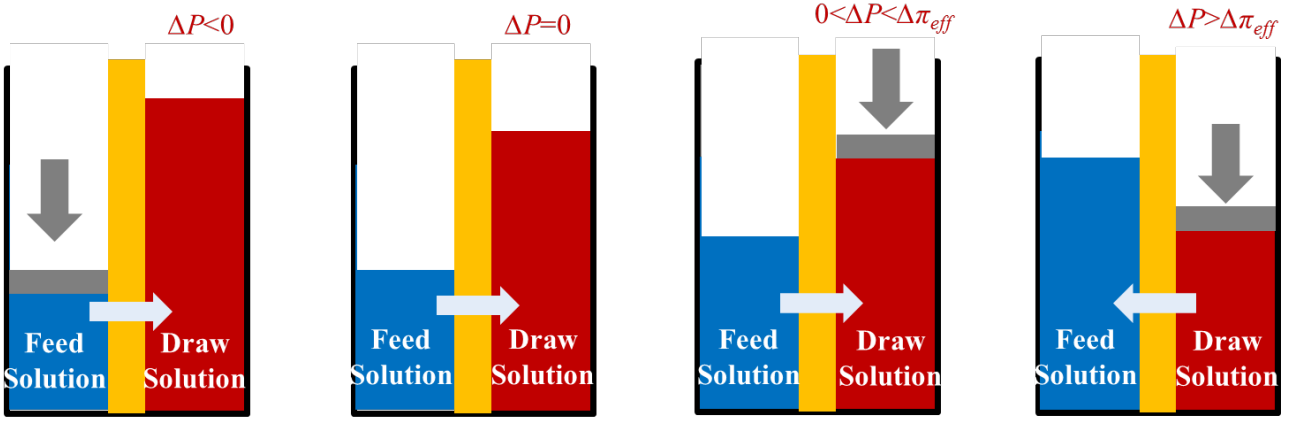


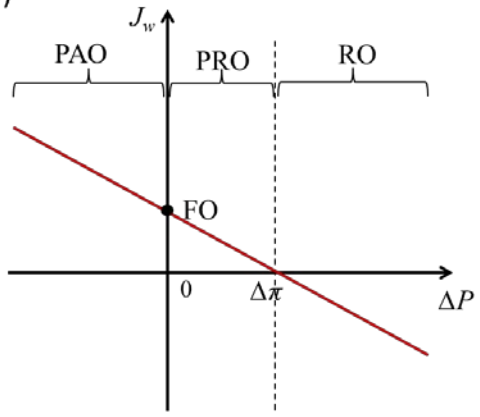
Figure 1. Annual number of publications on ODMPs and membrane fouling in ODMPs since 2005. Data were obtained from Scopus on 7th Oct 2015. Keywords for searching are "Forward Osmosis or Pressure Retarded Osmosis" and "Forward Osmosis or Pressure Retarded Osmosis and Fouling" respectively. In searched results, the document type does not include Short Survey, Erratum, Letter, Conference Review, and Conference Paper.

(a)



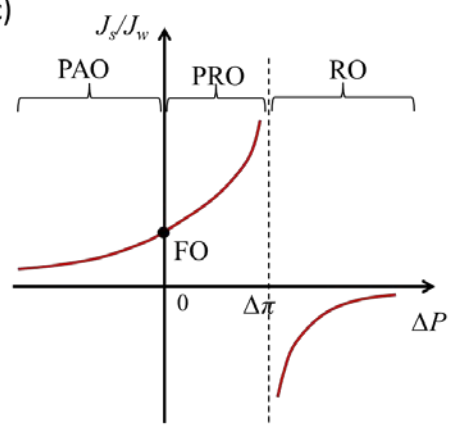
Pressure Assisted Osmosis (PAO) | **Forward Osmosis (FO)** | **Pressure Retarded Osmosis (PRO)** | **Reverse Osmosis (RO)**

(b)



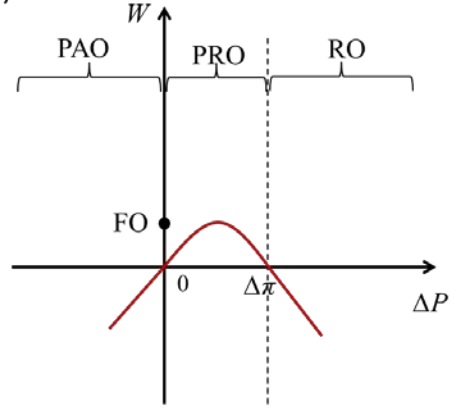
$$J_w = A(\Delta\pi_{eff} - \Delta P)$$

(c)



$$\frac{J_s}{J_w} = \frac{B}{A\beta R_g T}\left(1+\frac{\Delta P}{\Delta\pi_{eff}-\Delta P}\right) = \frac{B}{A\beta R_g T}\left(1+\frac{A\Delta P}{J_w}\right)$$

(d)



$$W = J_w \Delta P$$

Figure 2. Classification and characteristics of osmosis-related membrane separation processes. (a) Direction of water flows in RO, PRO, FO and PAO processes. In RO, water flows from high salinity draw solution (DS) to low salinity feed solution (FS) driven by the applied hydraulic pressure; in PRO and FO, water flows from low salinity FS to high salinity DS driven by the osmotic pressure; in PAO, water flows from low salinity FS to high salinity DS driven by both osmotic pressure and applied hydraulic pressure. (b) Water flux (J_w) magnitude, (b) specific solute flux (J_s/J_w) magnitude, and (c) power density (W) magnitude as a function of applied pressure in RO, PRO, FO and PAO processes.

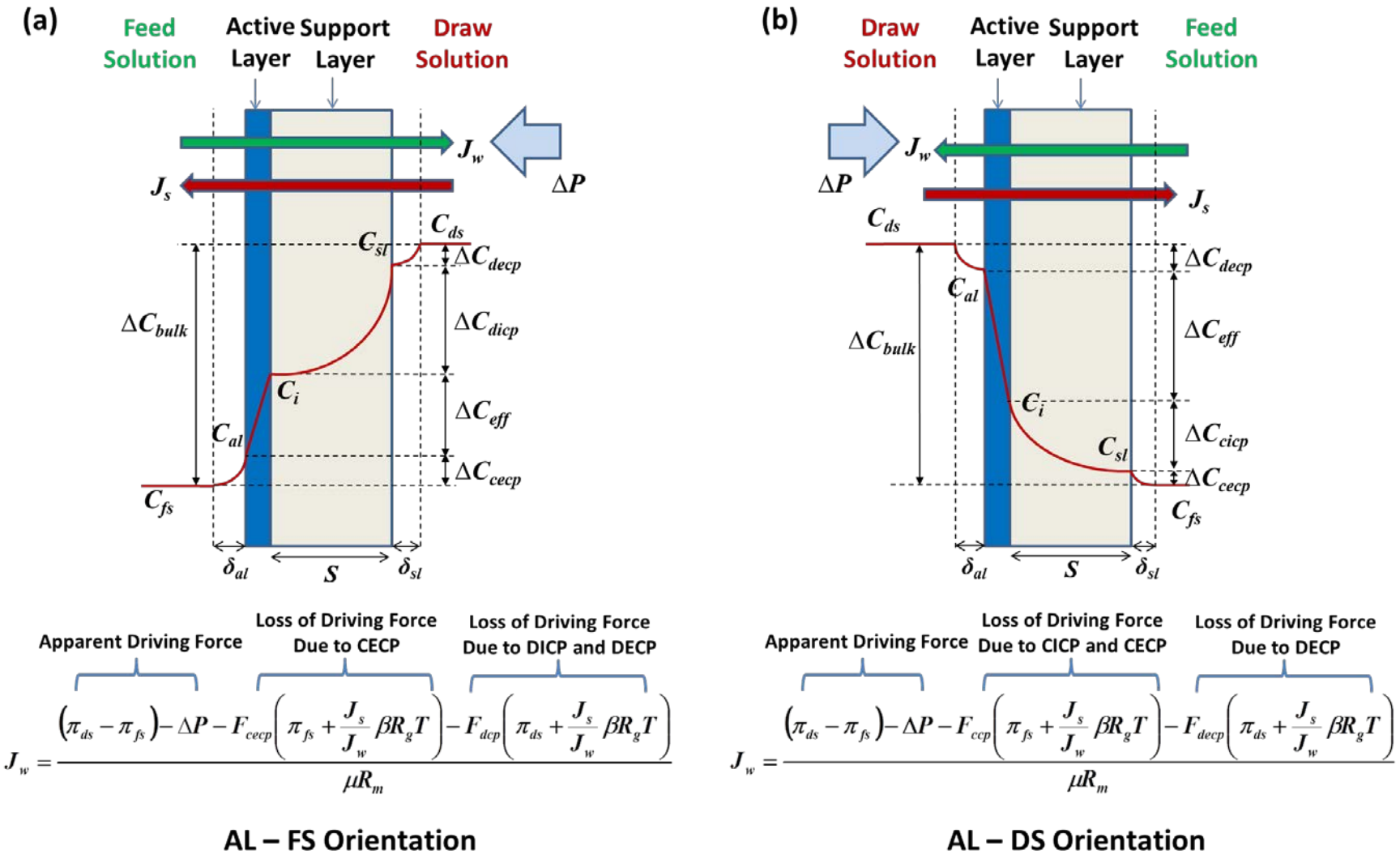


Figure 3. Schematic illustration of osmotic-resistance filtration model in ODMPs in (a) active-layer-facing-feed-solution (AL-FS) orientation and (b) active-layer-facing-draw-solution (AL-DS) orientation. All the driving forces represented by the concentration profile across the membrane due to ICP and ECP are specifically differentiated in accordance with the osmotic-resistance filtration model. The mathematic expressions of all the concentration polarization factors (F_{cecp}, F_{dcp}, F_{ccp} and F_{decp}) are described in Appendix

A. It is assumed that (1) the osmotic pressure is linearly proportional to the concentration and (2) the feed solution and draw solution contain the same solute.

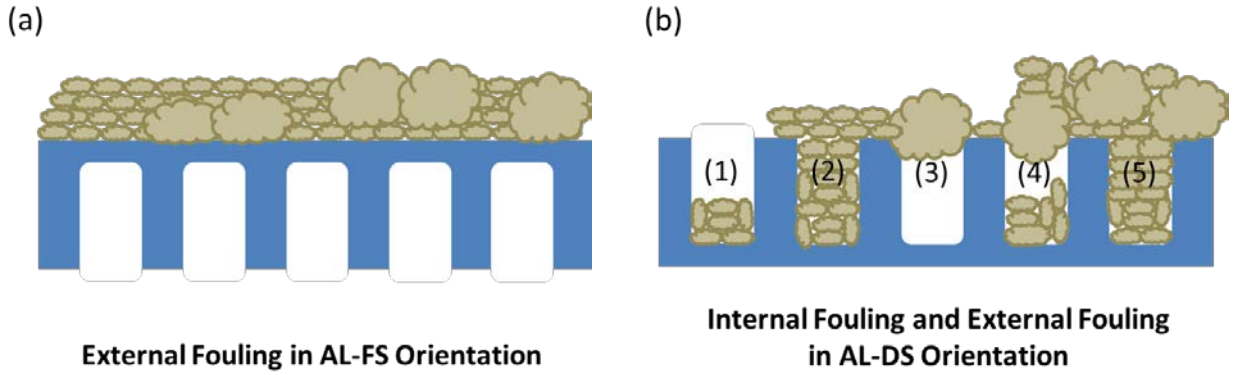


Figure 4. External fouling and internal fouling in ODMPs. (a) Only external fouling occurs in AL-FS orientation, (b) both external fouling and internal fouling occur in AL-DS orientation.

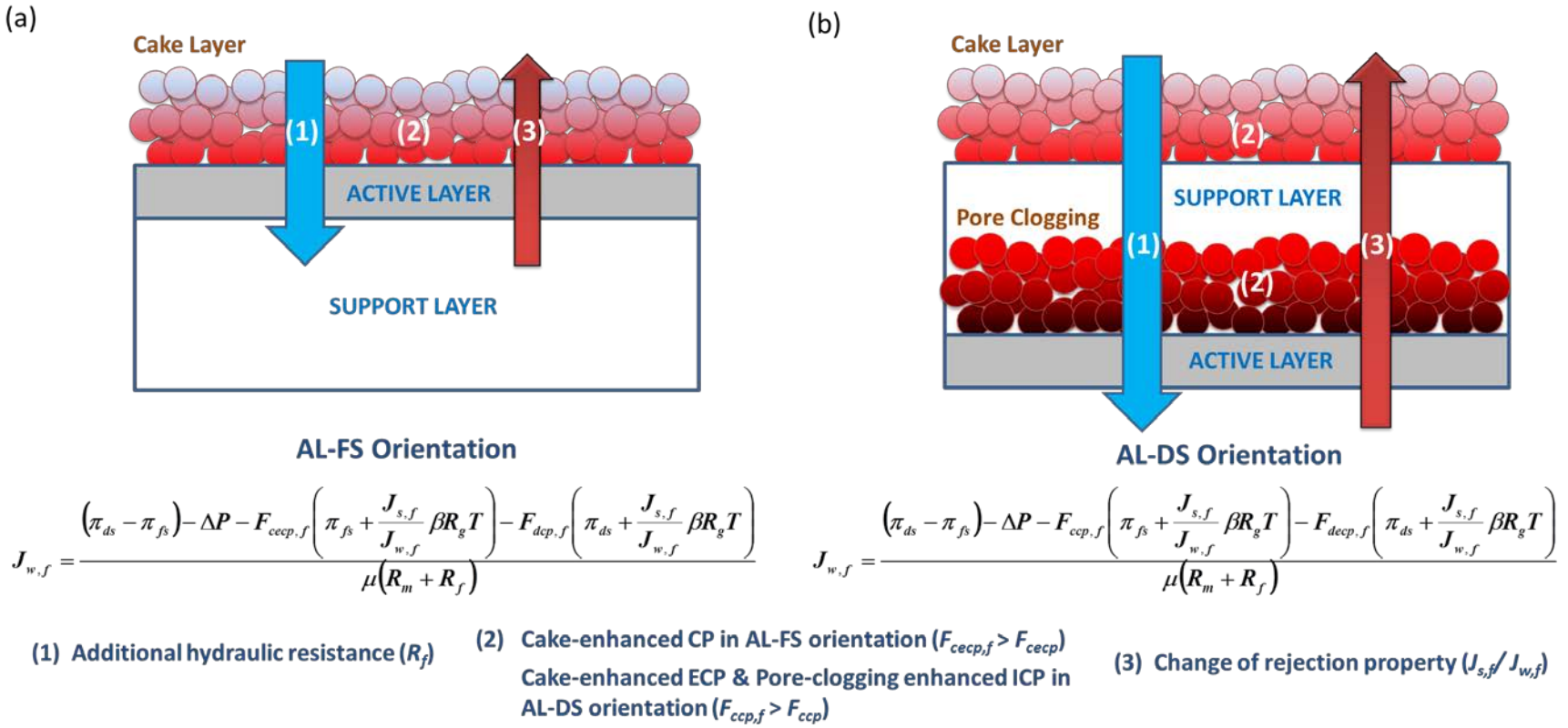


Figure 5. Schematic illustration of the influence of membrane fouling on water flux behavior in ODMPs according to the osmotic-resistance filtration model.

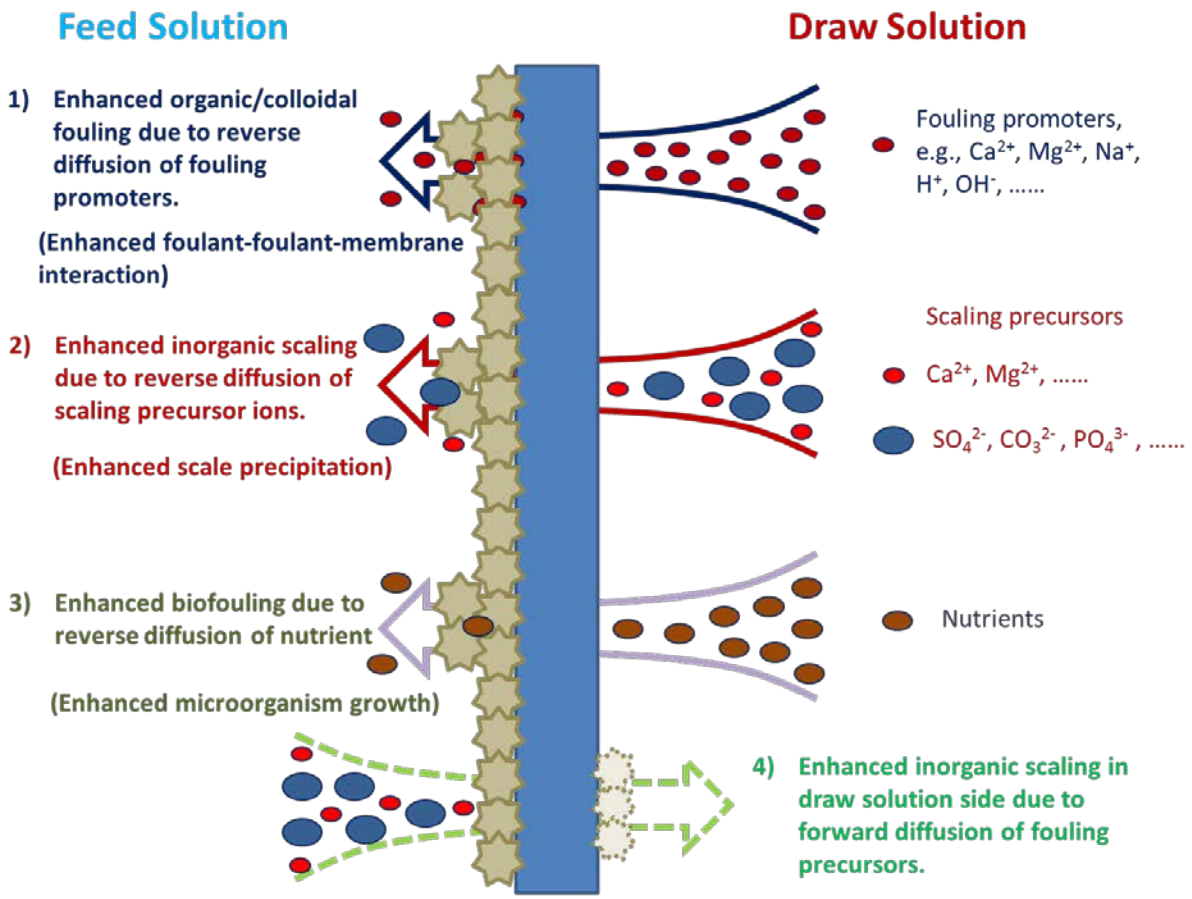


Figure 6. Schematic illustration of role of reverse solute diffusion (RSD) on enhanced membrane fouling in ODMPs.

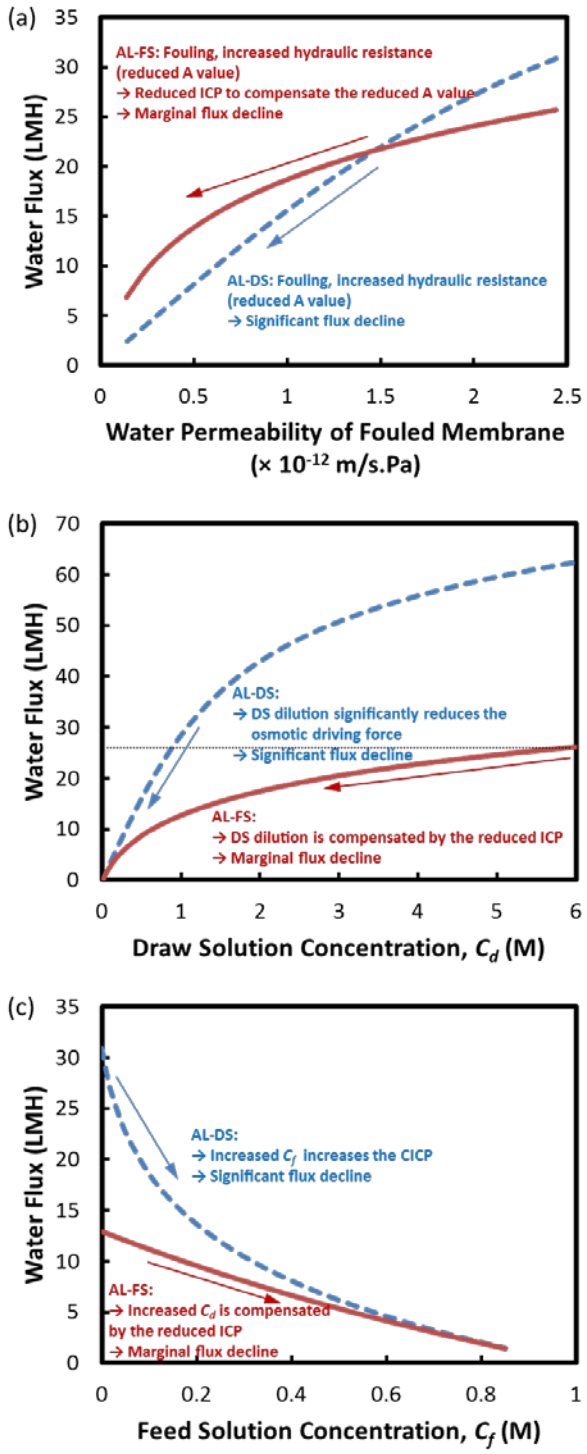


Figure 7. ICP self-compensation effect for the AL-FS orientation in different scenarios. (a) In the scenario of membrane fouling where water permeability is reduced. In the simulation, DS concentration is 5 M for AL-FS orientation and 1 M for AL-DS orientation respectively. (b) In the scenario of reduced DS concentration. (c) In the scenario of increased FS concentration. Other parameters for simulation: A value 2.14×10^{-12} m/s.Pa, B value 1.76×10^{-7} m/s, S value 456 μm, ΔP = 0 bar, C_{ds} = 1 M, and C_{fs} = 10 mM. Similar simulation was reported in ref. [27].

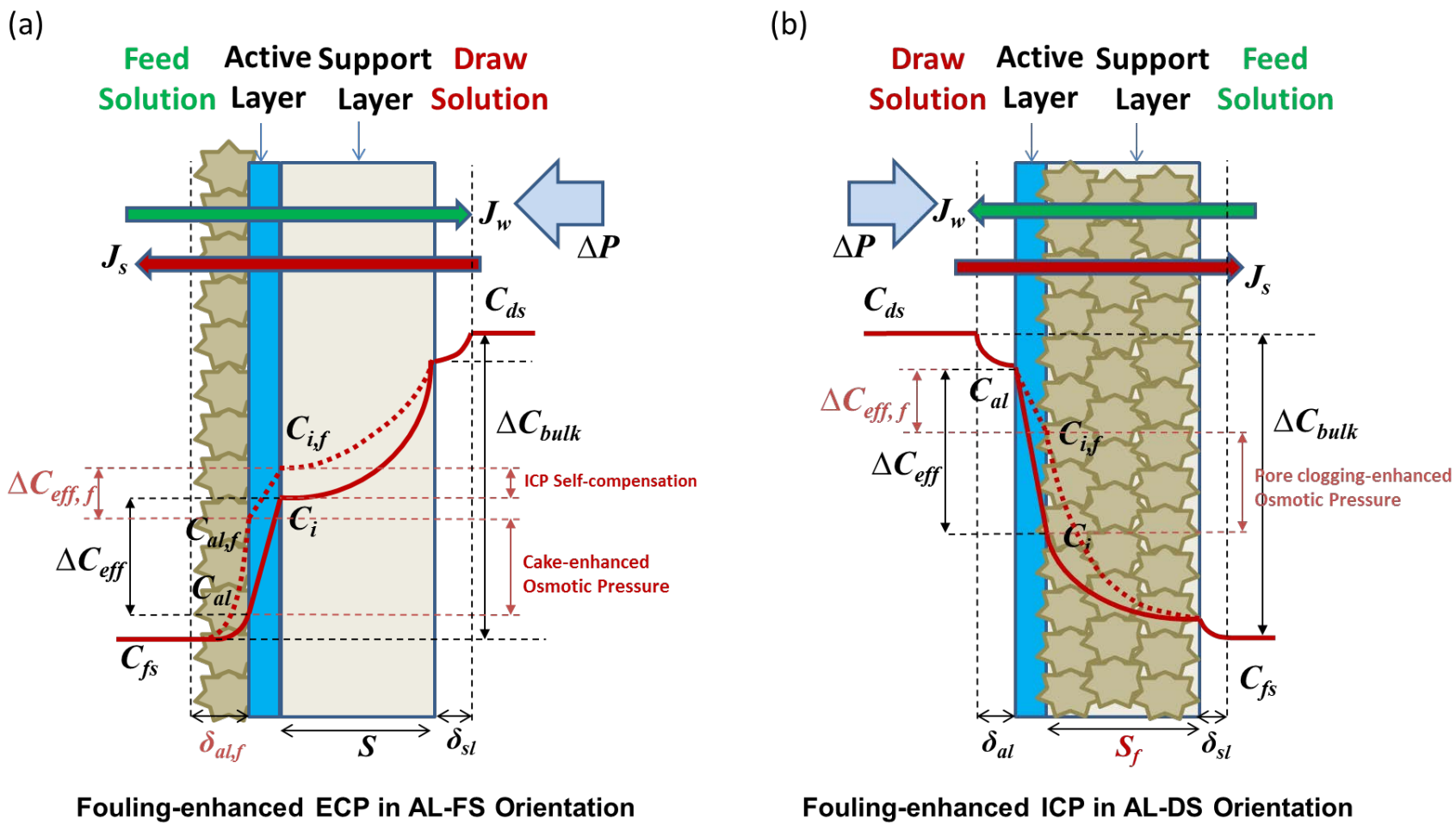


Figure 8. Schematic illustration of concentration profile across the membrane due to fouling-enhanced concentration polarization. The fouling-enhanced CP leads to the $\Delta C_{eff,f} < \Delta C_{eff}$. (a) Fouling-enhanced ECP in AL-FS orientation. Note that ICP self-compensation effect also plays a significant role in this orientation, which will moderate the flux decline. (b) Fouling-enhanced ICP in AL-DS orientation. Note that fouling-enhanced ECP in this orientation may behave similar to that in AL-FS orientation and thus is not illustrated. The solid line indicates the concentration profile before fouling, while the dotted line indicates the concentration profile after fouling.

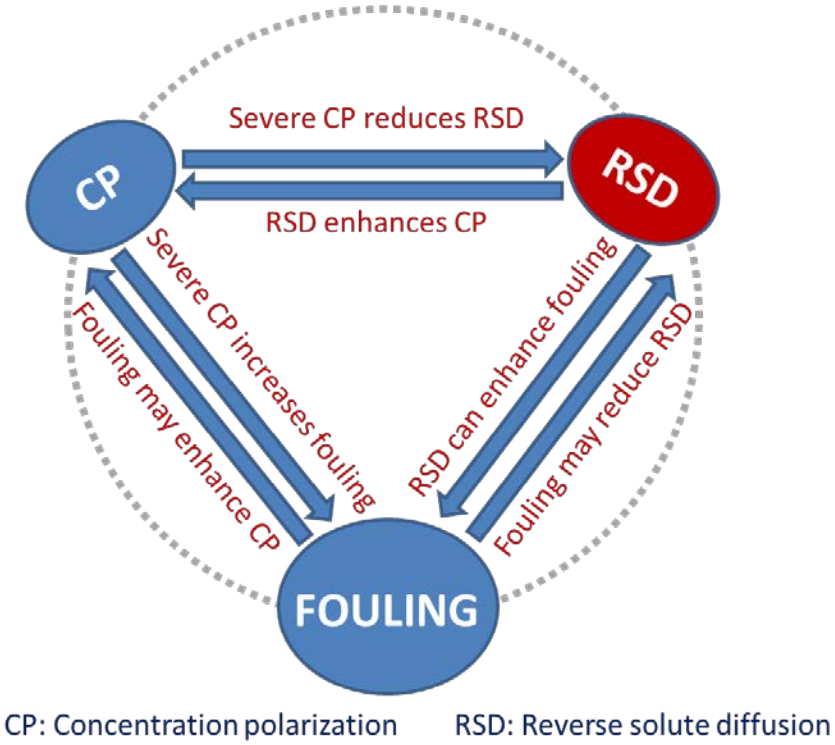


Figure 9. The intrinsic interrelationship among membrane fouling, concentration polarization (CP) and reverse solute diffusion (RSD) in ODMPs.

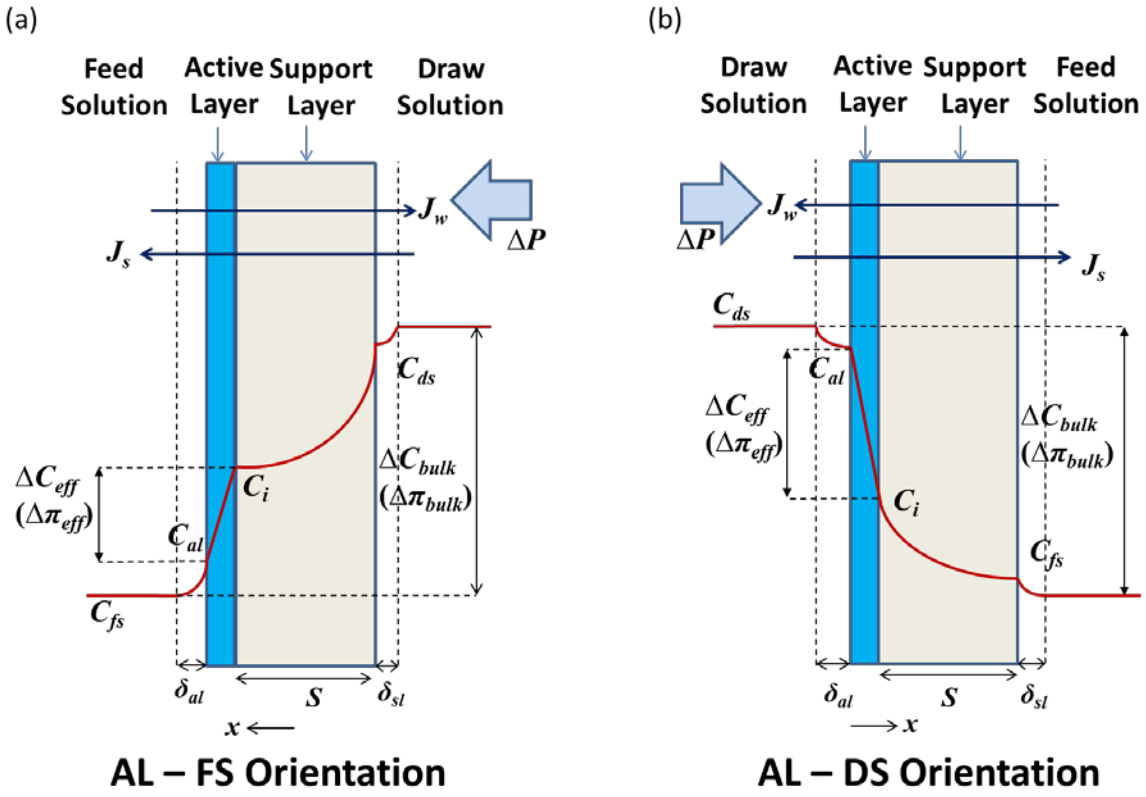


Figure A1. Concentration profile across the membrane due to ICP and ECP. Assuming the draw solution and feed solution contain the same solute.

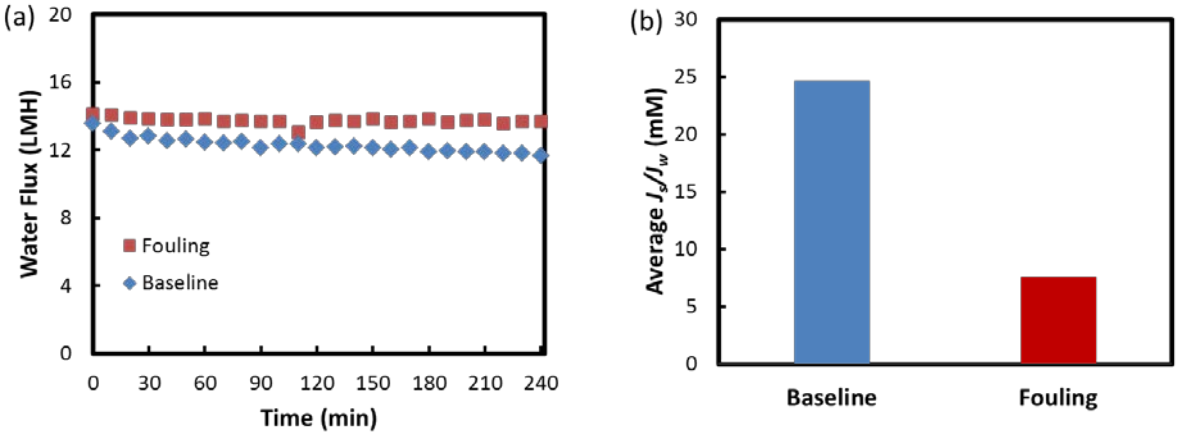


Figure B1. Enhanced water flux in humic acid fouling test due to fouling-reduced concentration polarization (CR-CP). (a) water flux in baseline test and humic acid fouling test in FO process, and (b) the average J_s/J_w in baseline test and fouling test. Fouling experimental conditions: feed solution only contained 10 mg/L humic acid in DI water, draw solution 0.5 M NaCl, cross-flow velocity 23.2 cm/s, AL-FS membrane orientation, and hand-casted TFC-PA FO membrane (the properties are reported in ref. [156]). In baseline test, DI water was used as feed solution.