Forward Osmosis for Desalination and Wastewater Treatment

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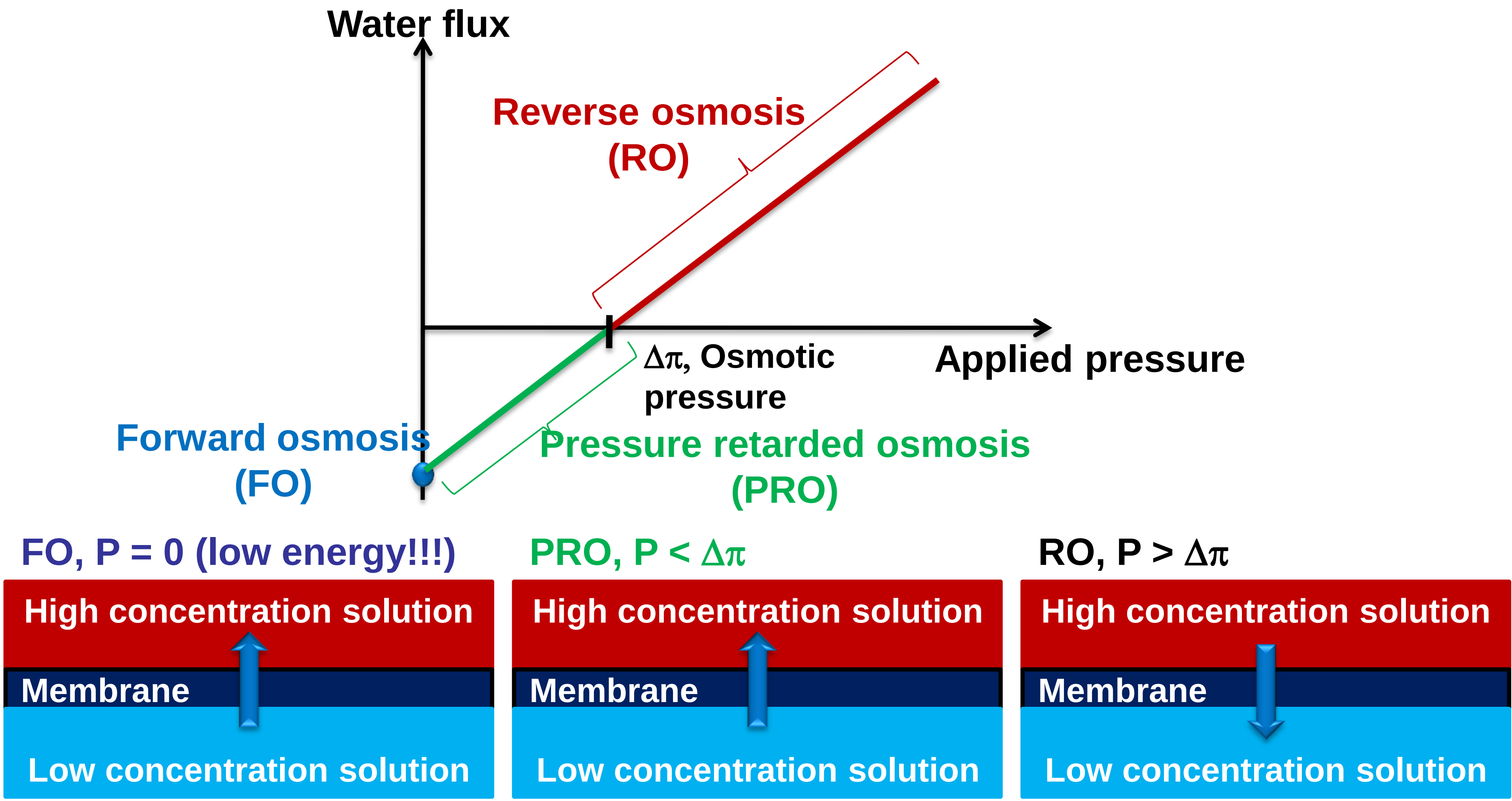
Outline

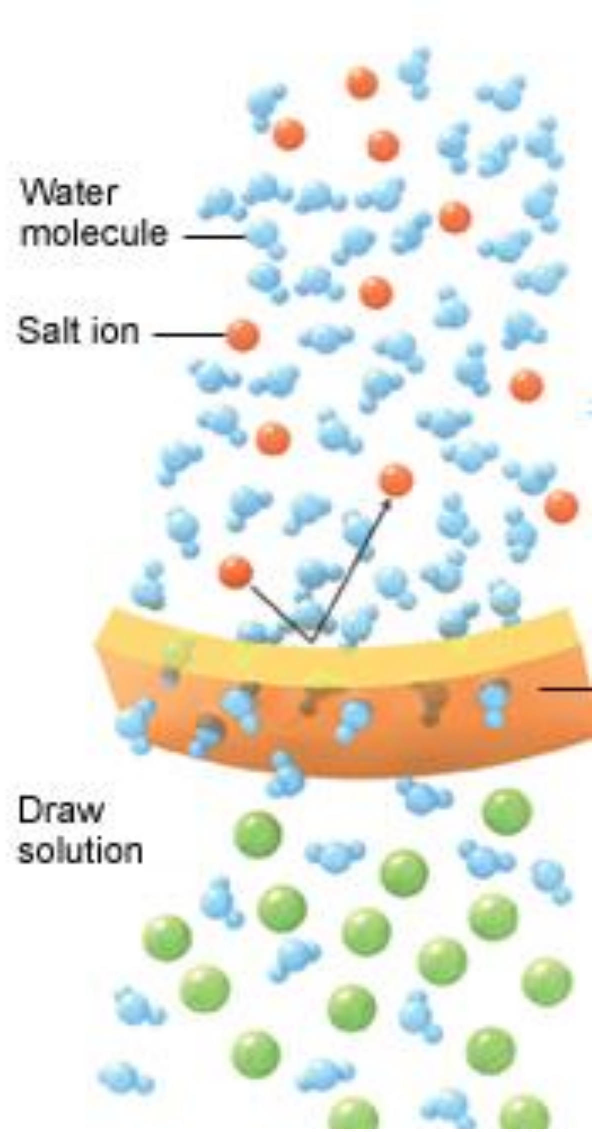
- Forward osmosis (FO) background
- Potential FO applications in Hong Kong
- FO membrane performance
- Conclusion

RO, FO, & PRO



Xu et al, JMS *348, 298-309, (2010)*

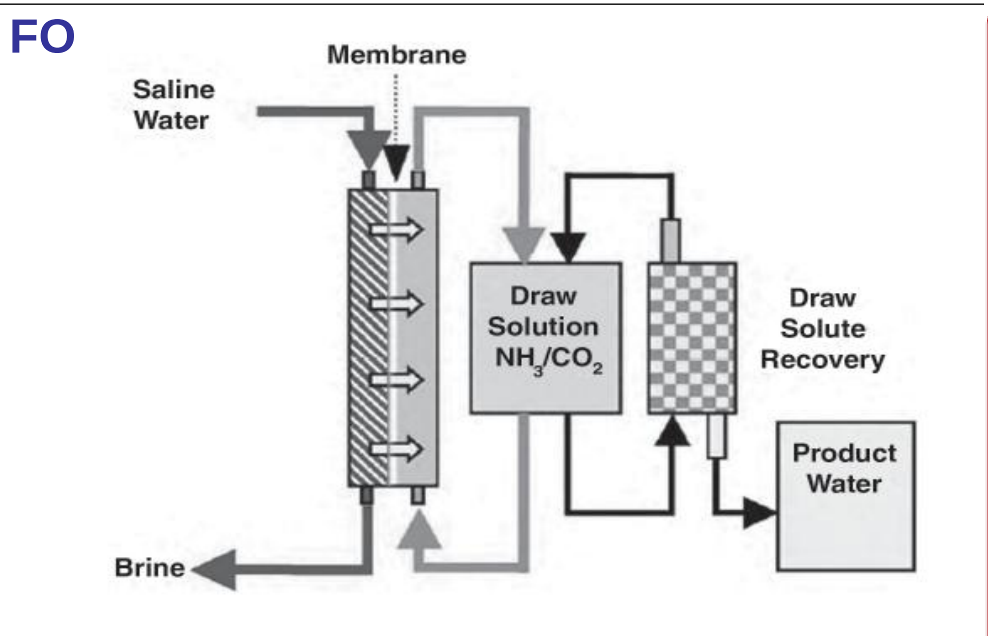
Forward osmosis

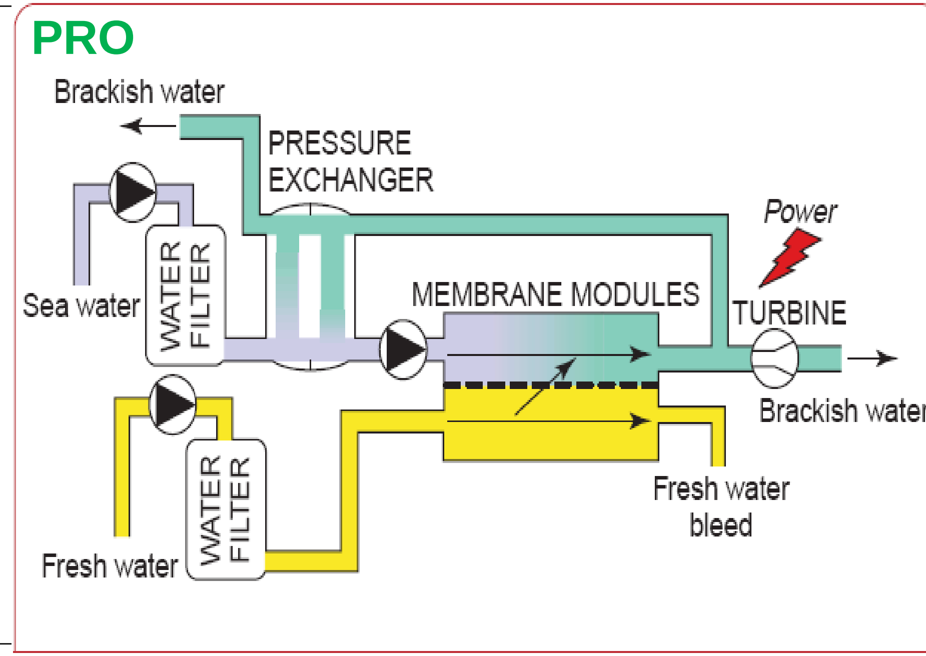


- Key features
  - High rejection (like RO membranes)
  - Low pressure (**low energy consumption**)
  - Low fouling
  - Potential for resource recovery
- Potential applications
  - Seawater desalination
  - Wastewater treatment
  - Brine (and other difficult streams) treatment
  - Food processing

The National Geography Magazine
http://ngm.nationalgeographic.com/big-idea/09/desalination-pg2

Forward osmosis
Pressure retarded osmosis



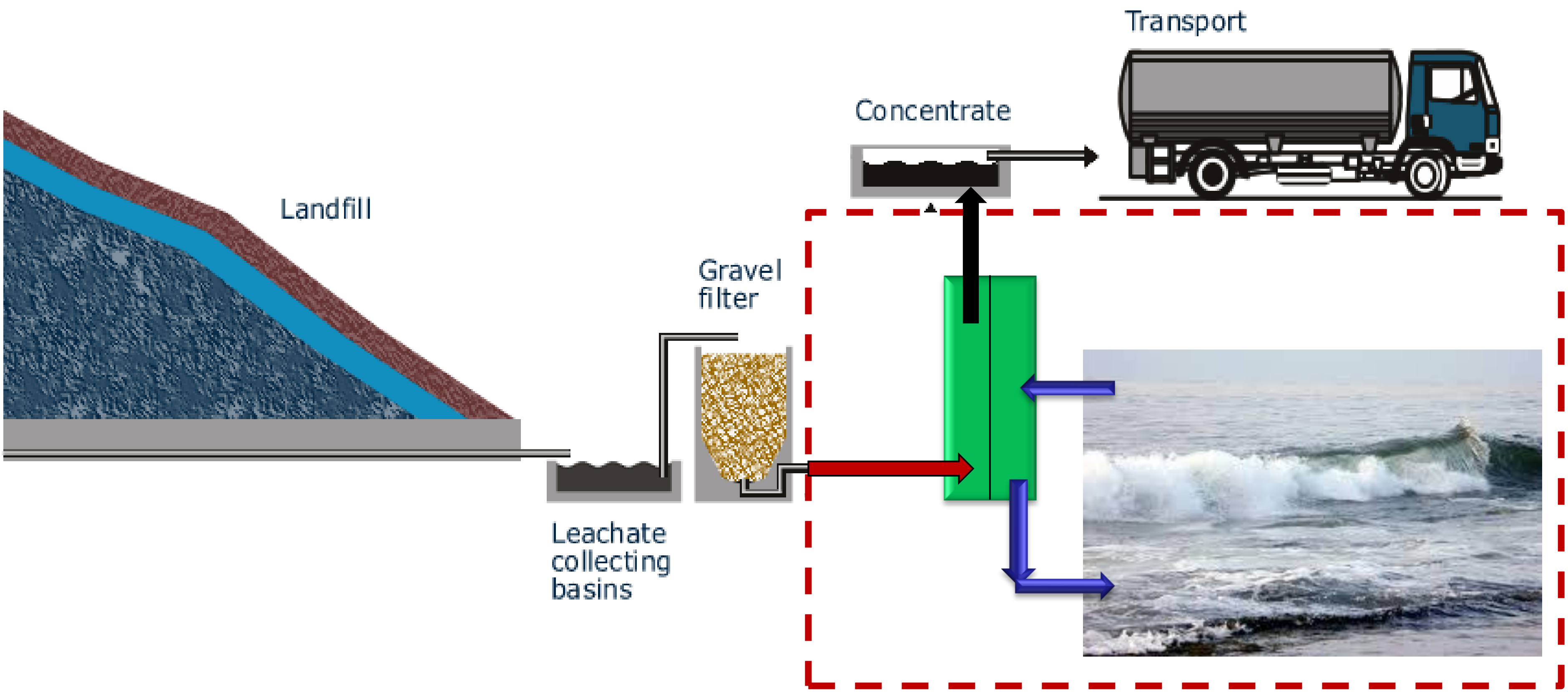


McCutcheon, J. R.; McGinnis, R. L.; Elimelech, M., A novel ammonia-carbon dioxide forward (direct) osmosis desalination process. *Desalination 2005, 174, (1), 1-11.*

Aaberg, R.J., *Osmotic Power: A new and powerful renewable energy source?* Refocus, 2003. 4(6): p. 48-50.

Potential applications in Hong Kong

Landfill leachate treatment

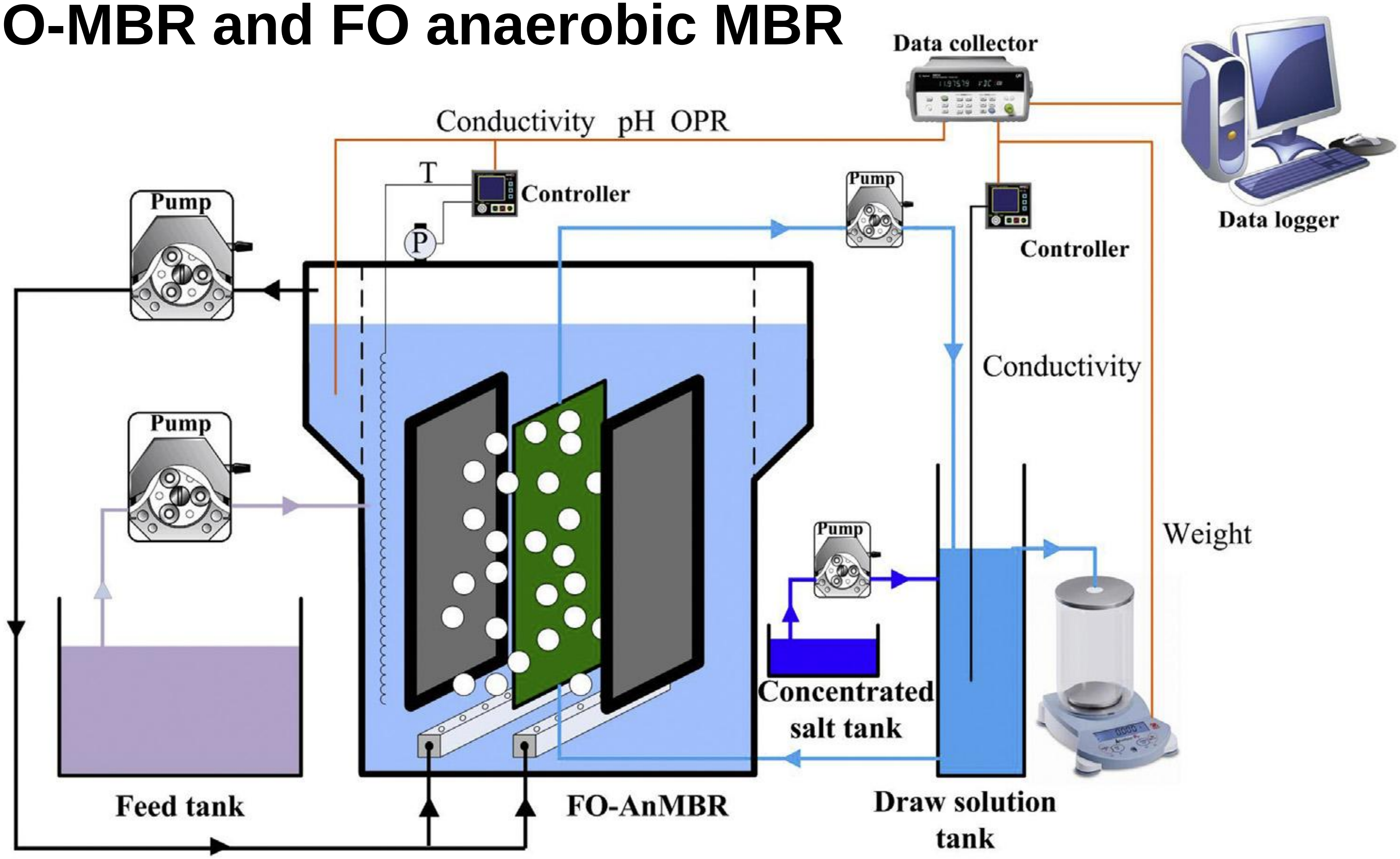


http://www.zawsachsen.de/tl_files/sickwa/sickwa-plan-eng.png

Potential applications in Hong Kong

Wastewater reclamation and energy recovery

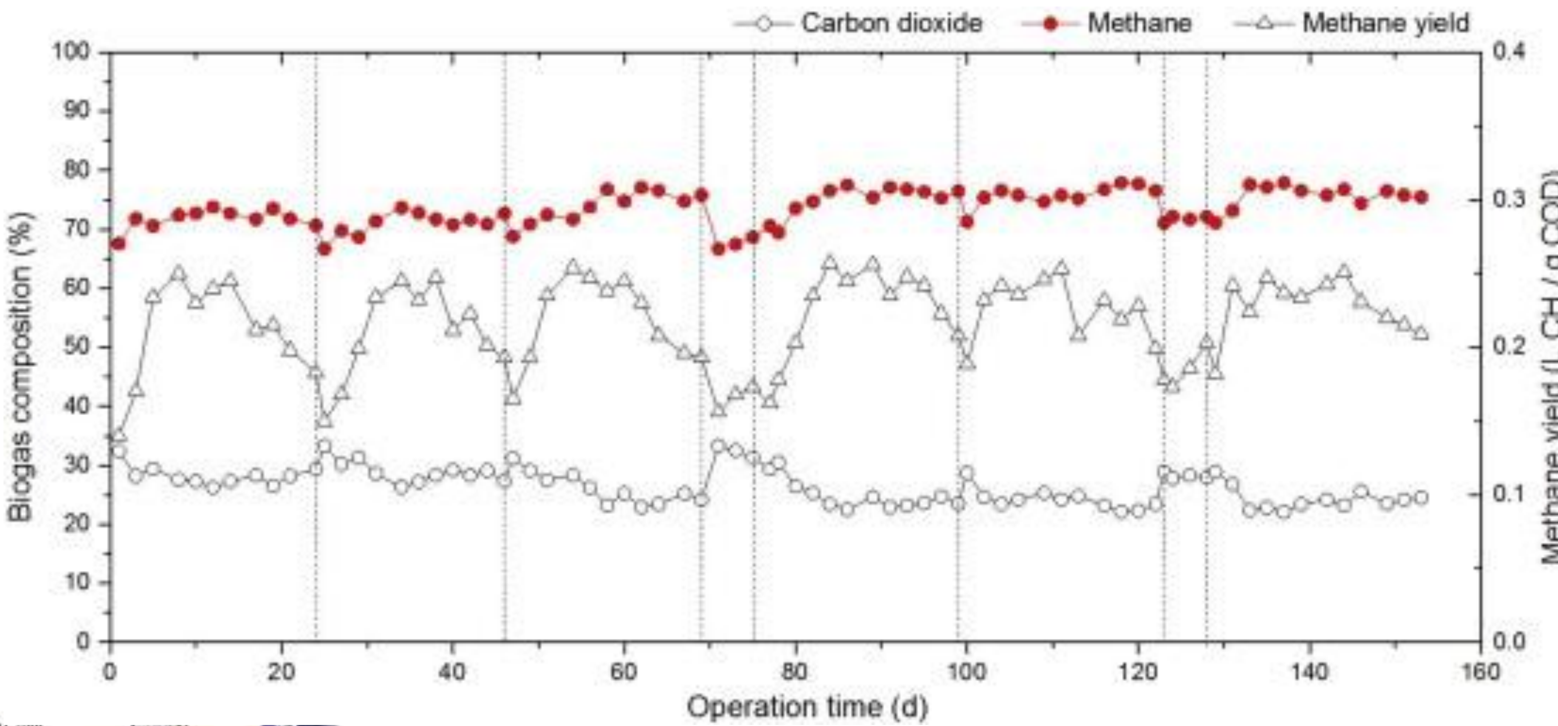
FO-MBR and FO anaerobic MBR

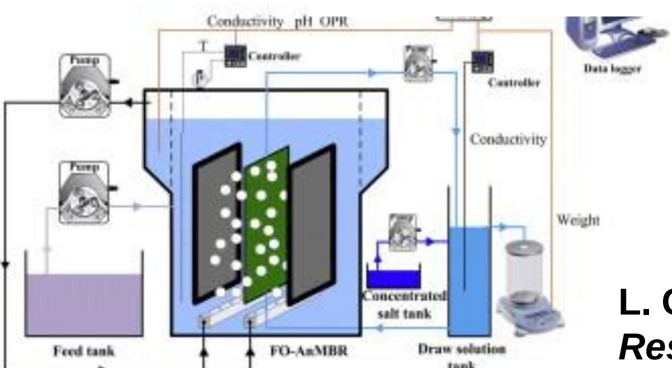


L. Chen, Y. Gu, C. Cao, J. Zhang, J.-W. Ng and C.Y. Tang, *Water Research*, 2014, 50, 114-123.

Potential applications in Hong Kong

Wastewater reclamation and energy recovery



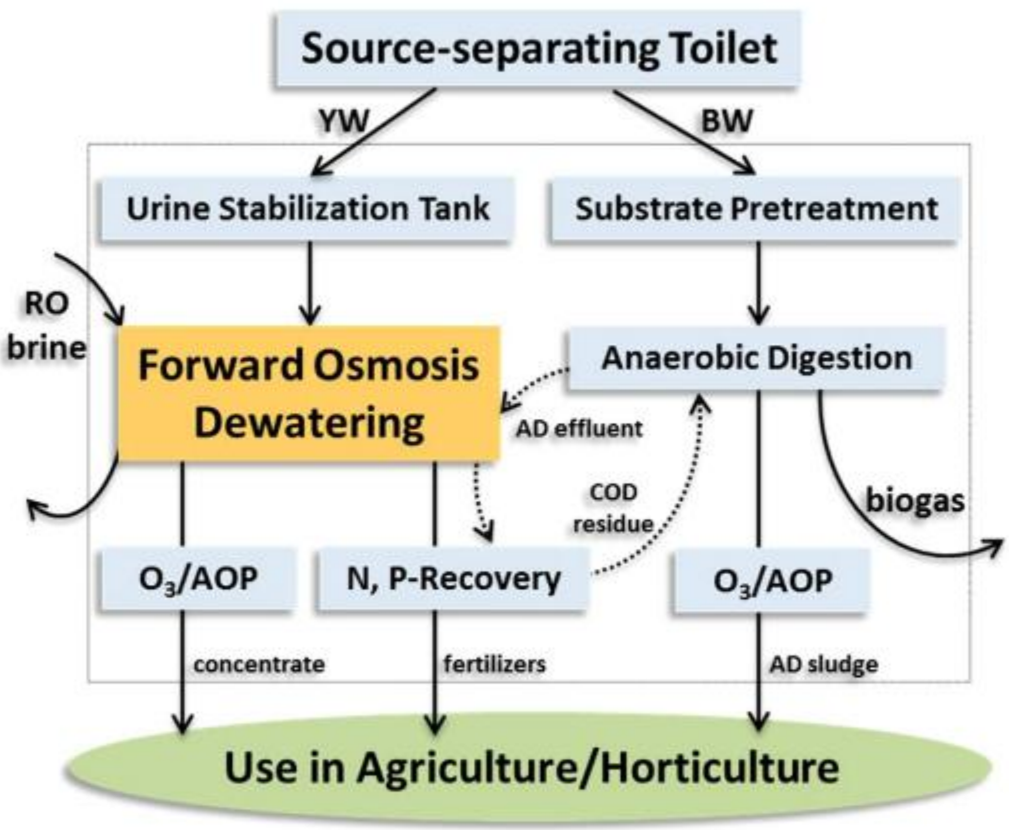


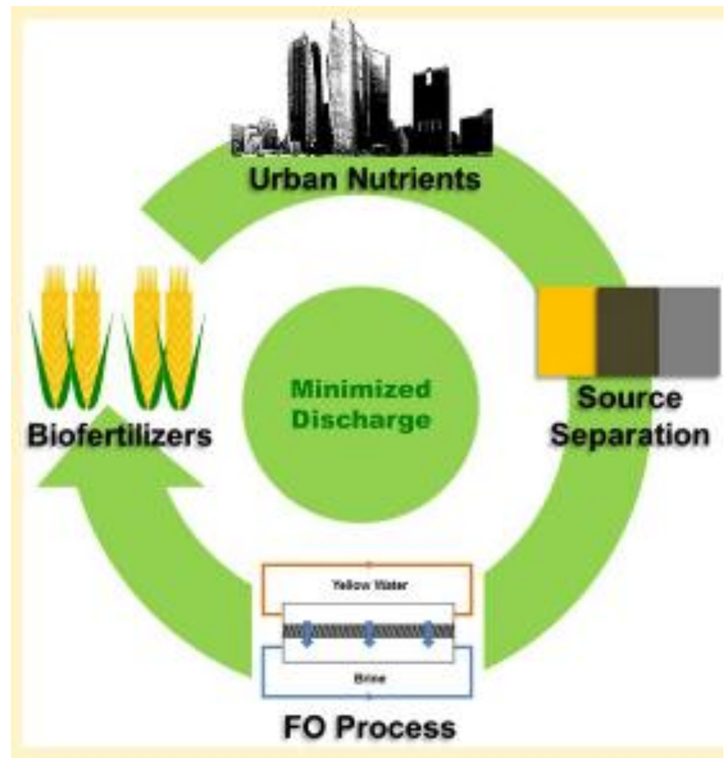
L. Chen, Y. Gu, C. Cao, J. Zhang, J.-W. Ng and C.Y. Tang, *Water Research*, 2014, 50, 114-123.

Potential applications in Hong Kong

Waste volume reduction and resource recovery

Recovering Nutrients (N, K, P) from Urban Source-Separated Urine

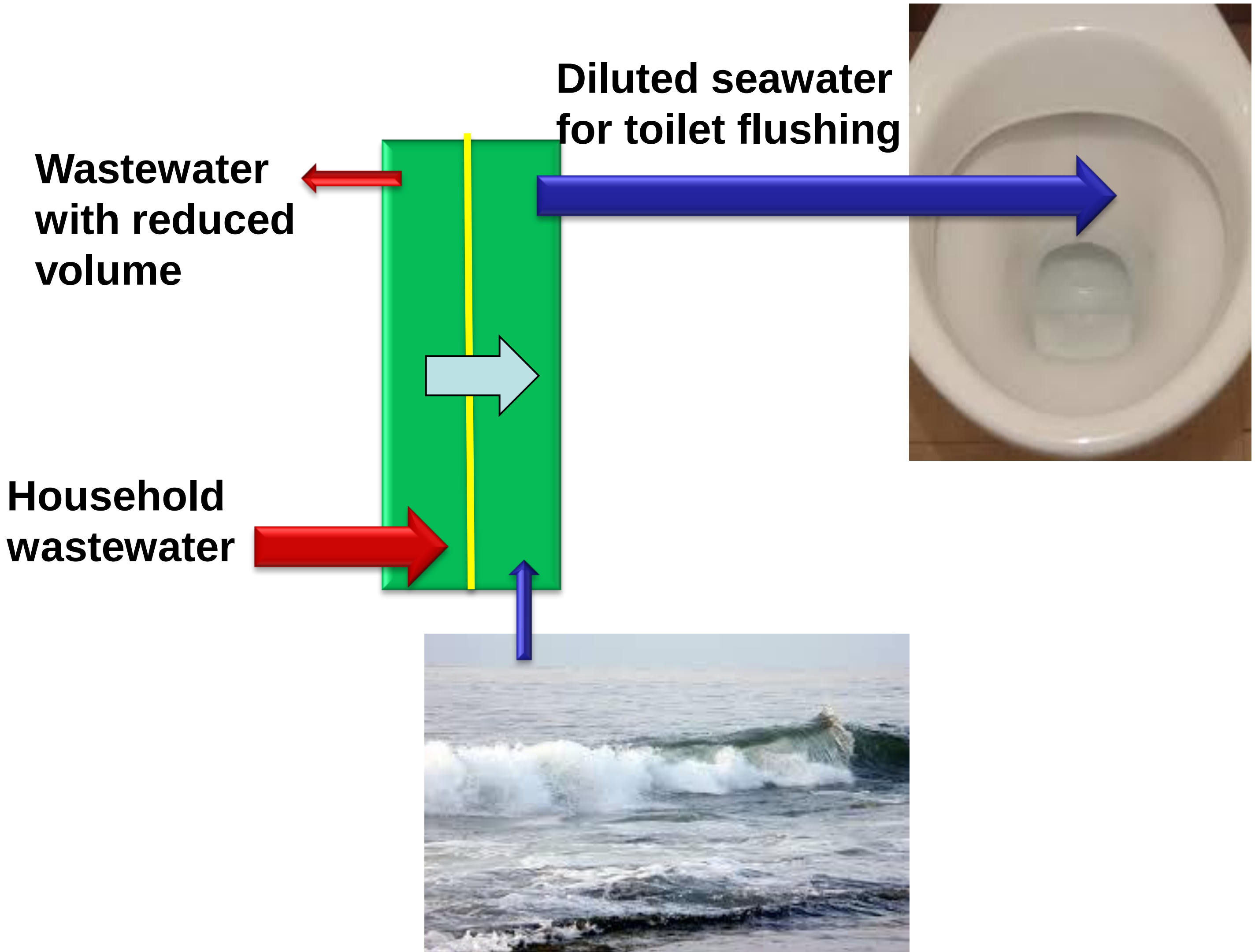




J. Zhang, Q. She, V. W. C. Chang, C. Y. Tang and R. D. Webster, ***Environmental Science & Technology*****, 2014, 48**, 3386-3394.

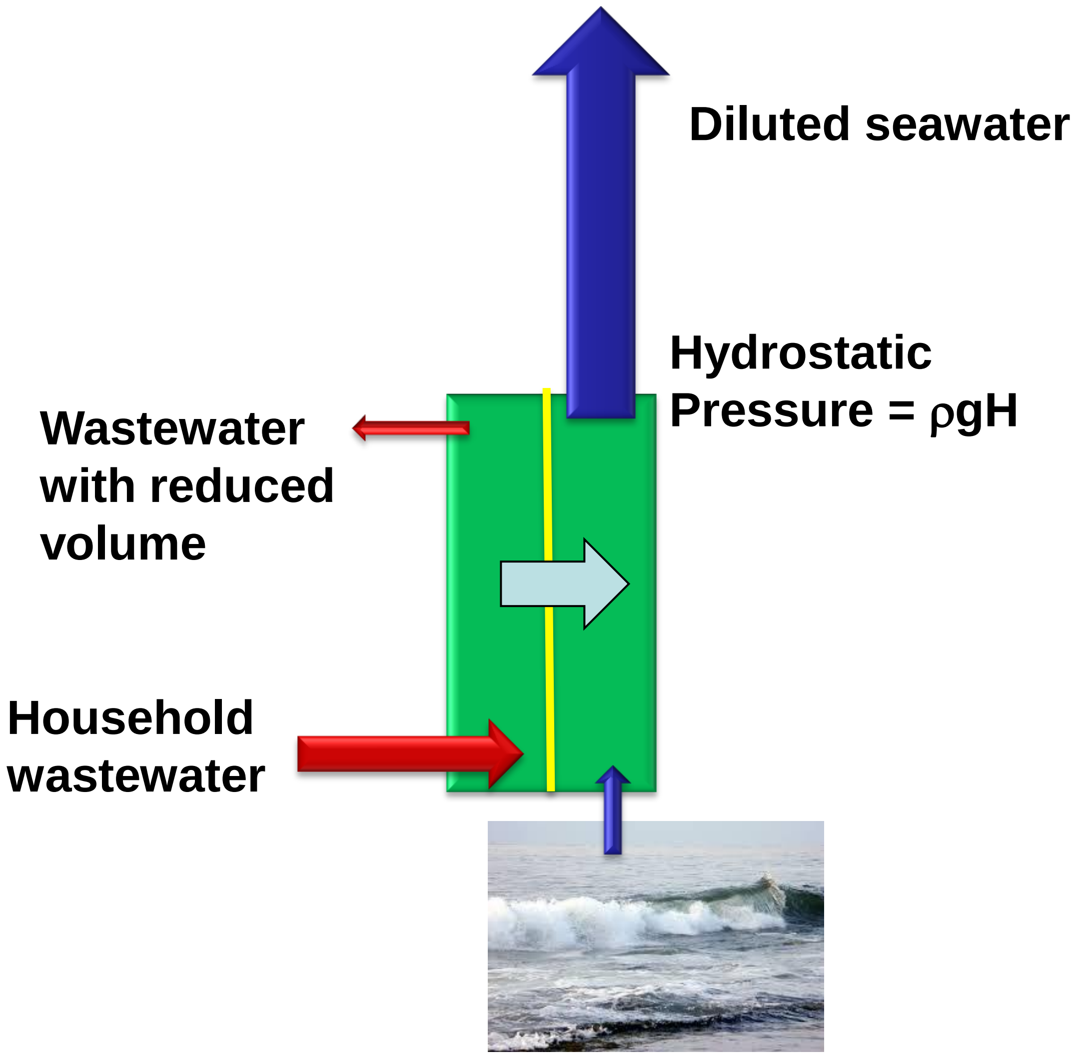
Potential applications in Hong Kong

Reclaim wastewater for toilet flushing



Potential applications in Hong Kong

Osmotic pump for reducing pumping energy



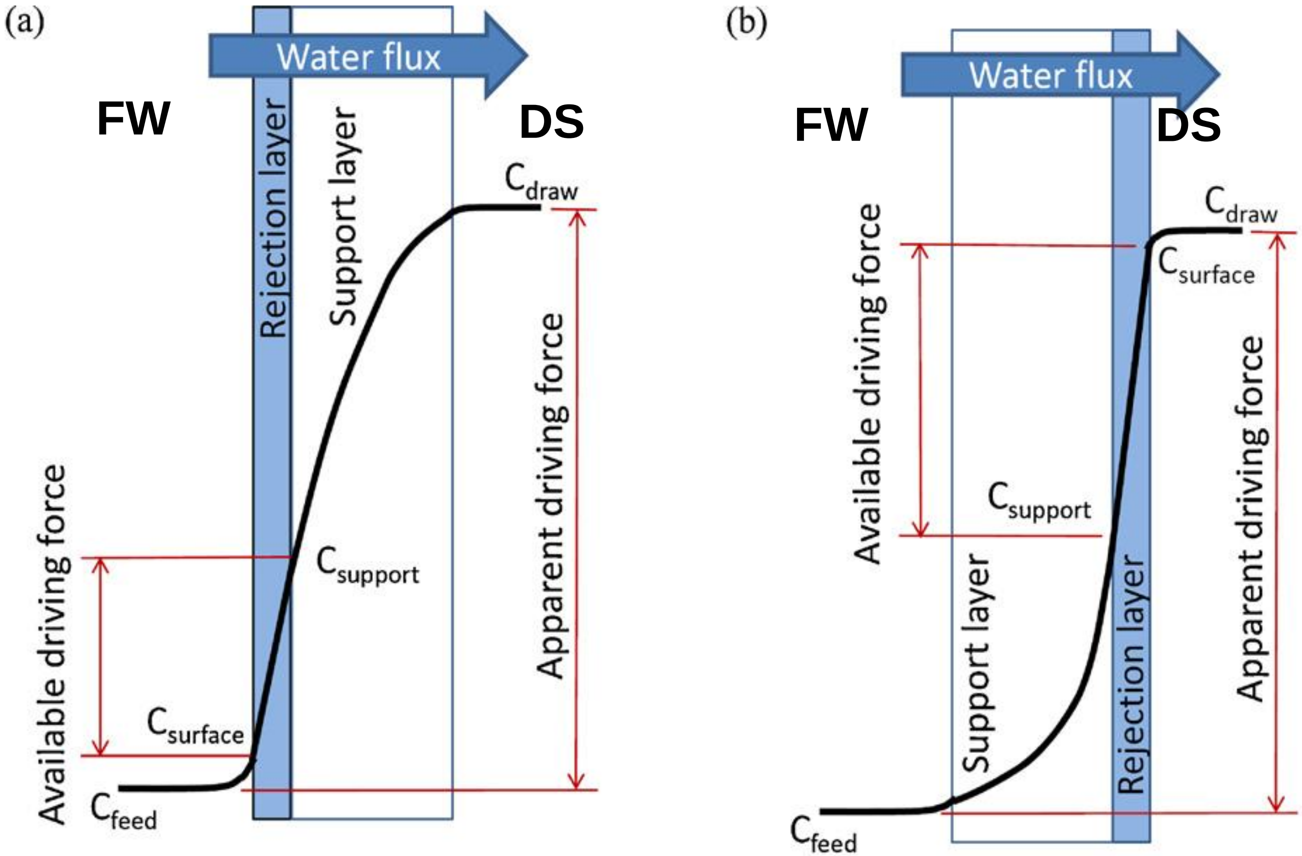
Osmotic pressure π of seawater = 2.5 MPa

As long as P < π Osmotic condition will be maintained

Osmotic pumping can provide a hydrostatic head of up to 250 m!

→ Enough pressure to deliver seawater w/o mechanical pumping for a 50-storey building

FO performance modeling



Ideal FO membranes

Rejection layer
- **High A value**
- **Low B value**

Support layer
- **Small S value**
- **Thinner**
- **more porous**
- **lower tortuosity**

$$J_w = \frac{D}{S}\left(\ln \frac{B + A\pi_{draw} - J_w}{B + A\pi_{feed}}\right)$$

$$J_w = \frac{D}{S}\left(\ln \frac{B + A\pi_{draw}}{B + J_w + A\pi_{feed}}\right)$$

$$S = \frac{\tau \cdot t}{\varepsilon}$$

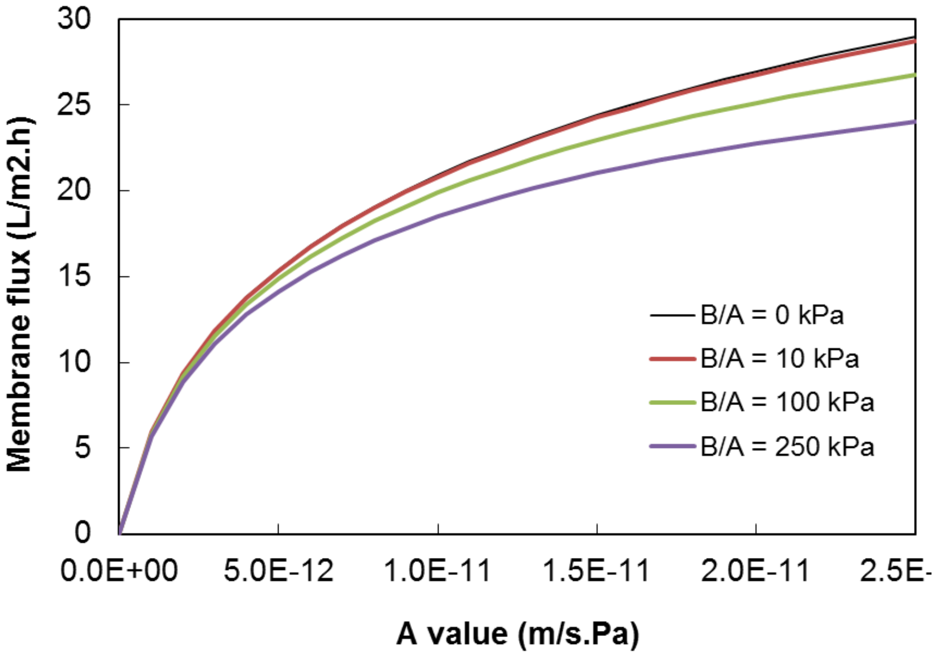
Lee et al. ***JMS 1981, 8, 141-171.***
Loeb et al. ***JMS 1997, 129, 243-249.***

C. Y. Tang et al., ***JMS 2010, 354, 123-133.***

FO performance simulation

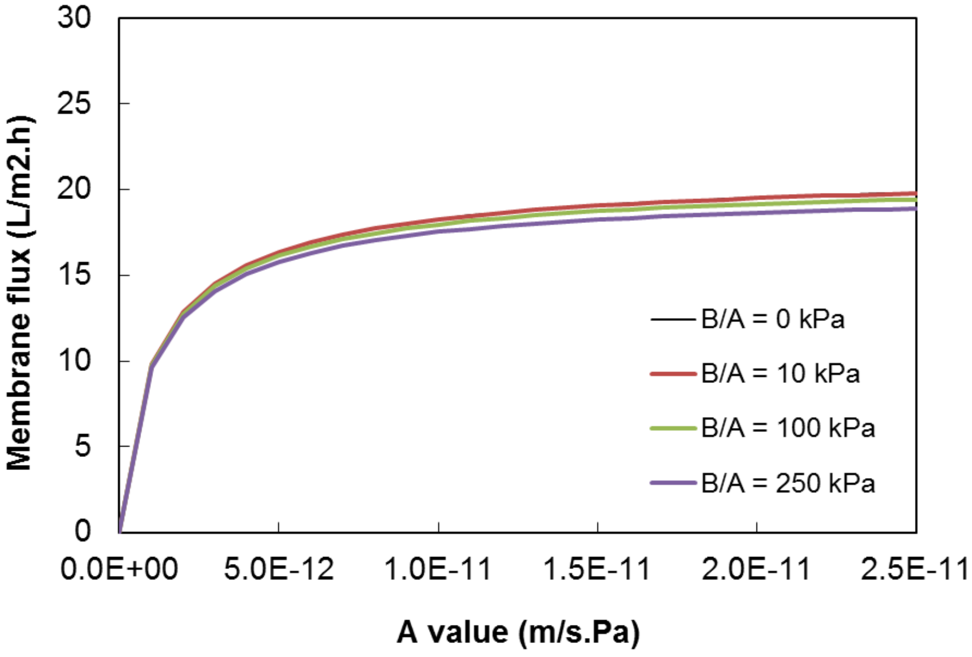
Wastewater treatment scenario

Osmotic pressure:
Feed: 50 kPa (wastewater)
Draw: 2.5 MPa (seawater)



Desalination scenario

Osmotic pressure:
Feed: 2.5 MPa (wastewater)
Draw: 10 MPa (seawater)

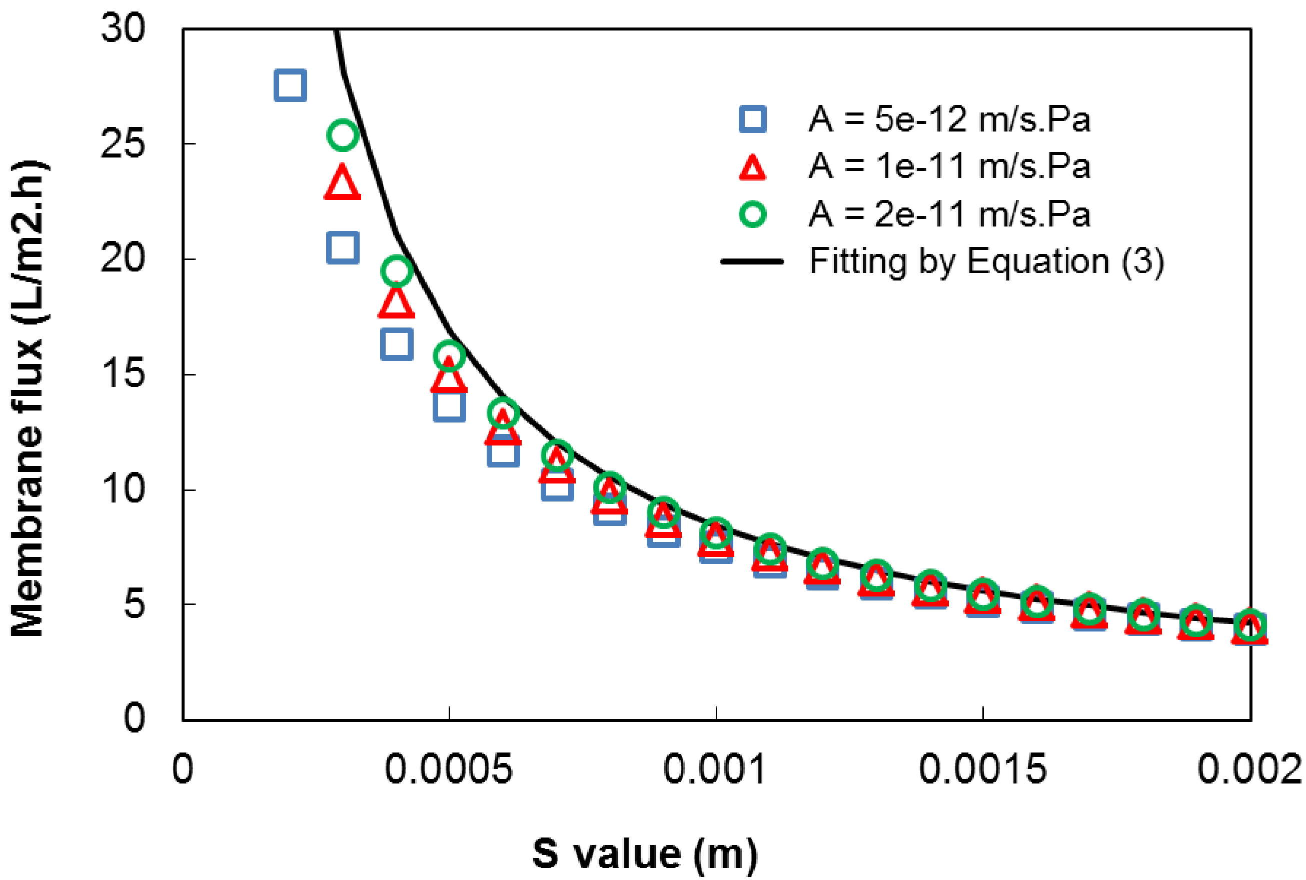


Other simulation conditions: S = 0.4 mm and D = 1.69 x 10-9 m2/s (NaCl).

FO performance simulation

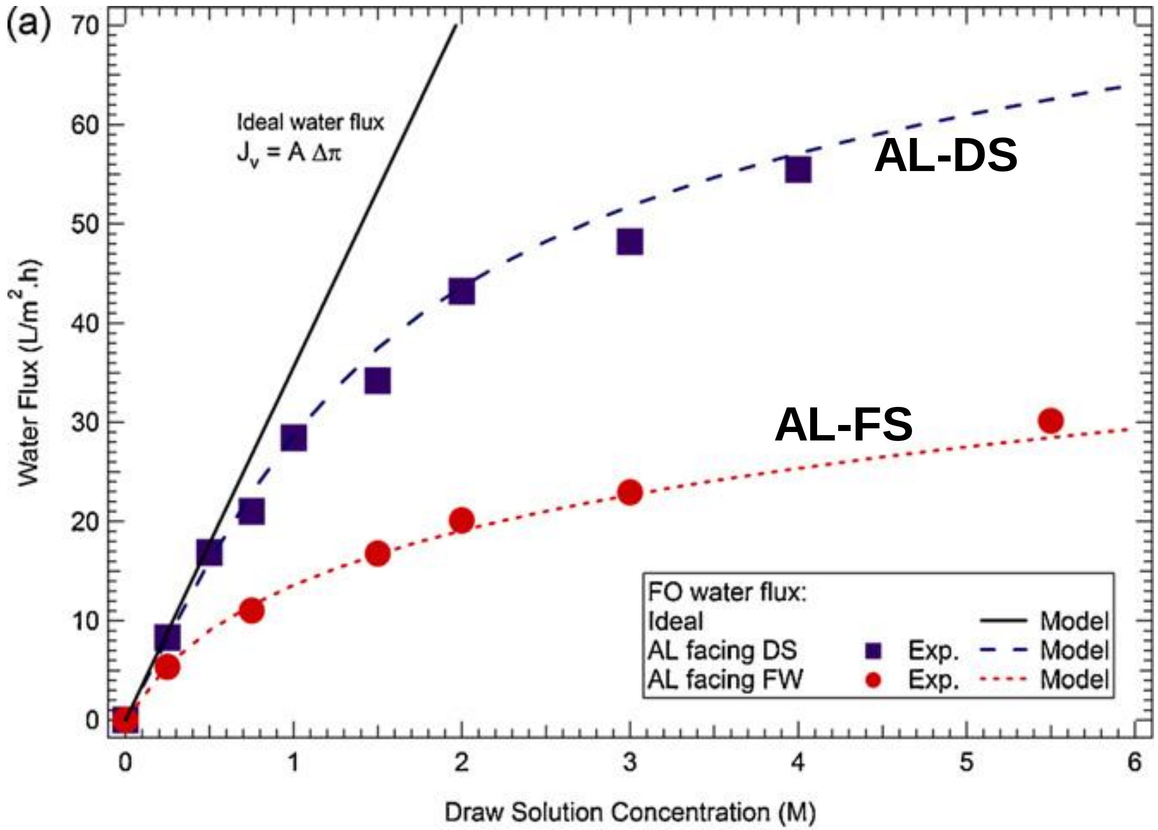
Desalination scenario

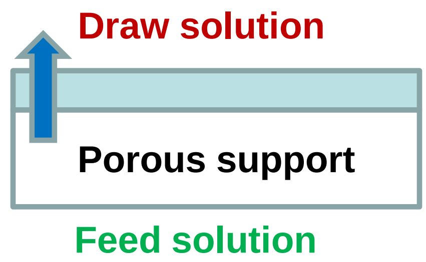
Feed: 2.5 MPa (wastewater) **Draw: 10 MPa (seawater)**

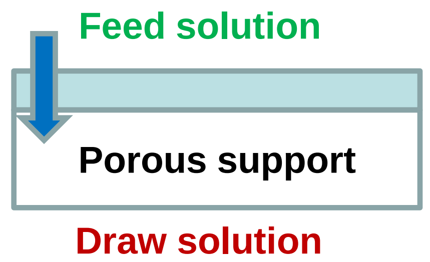


Model verification

FO water flux

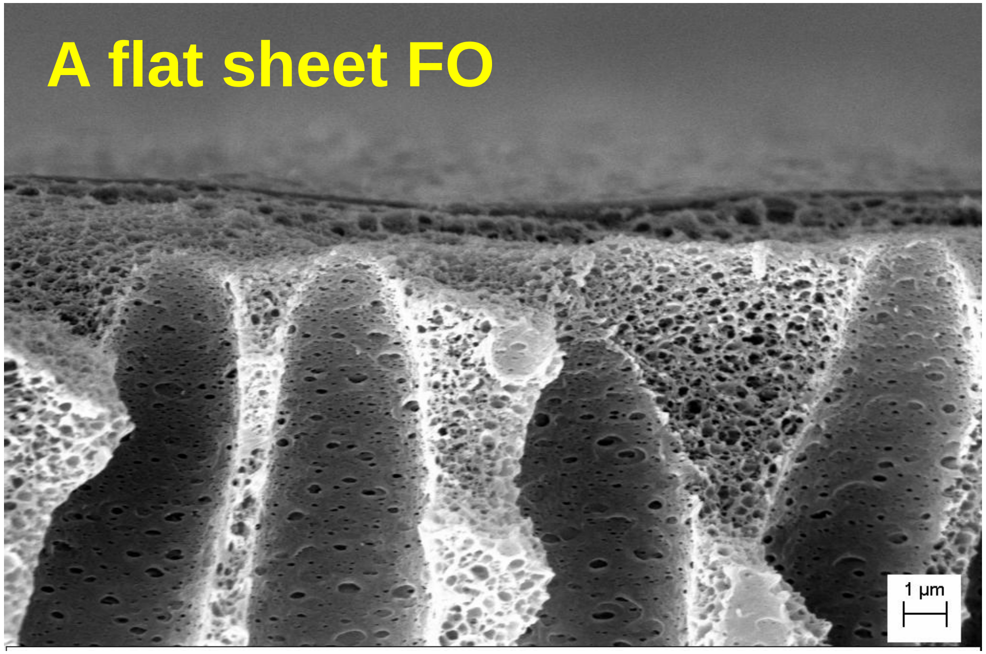


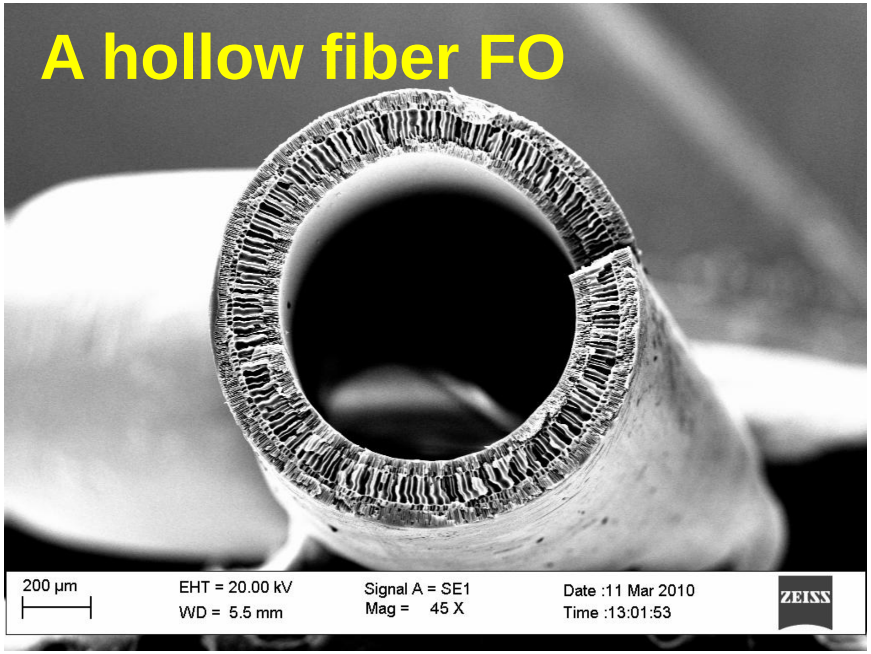




C. Y. Tang*; Q. She; W.C.L. Lay; R. Wang; Fane, A. G. *JMS 2010, 354, 123-133.*

FO fabrication – Thin film composite





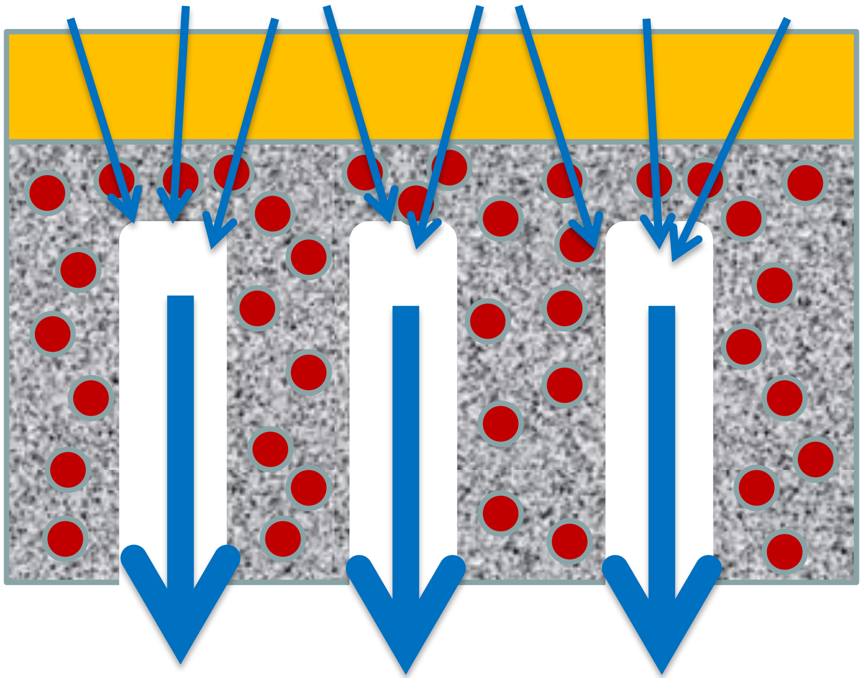
Wang, R.; Shi, L.; Tang, C. Y.; Chou, S.; Qiu, C.; Fane, A. G., Characterization of novel forward osmosis hollow fiber membranes. *Journal of Membrane Science 2010, 355, 158–167.*

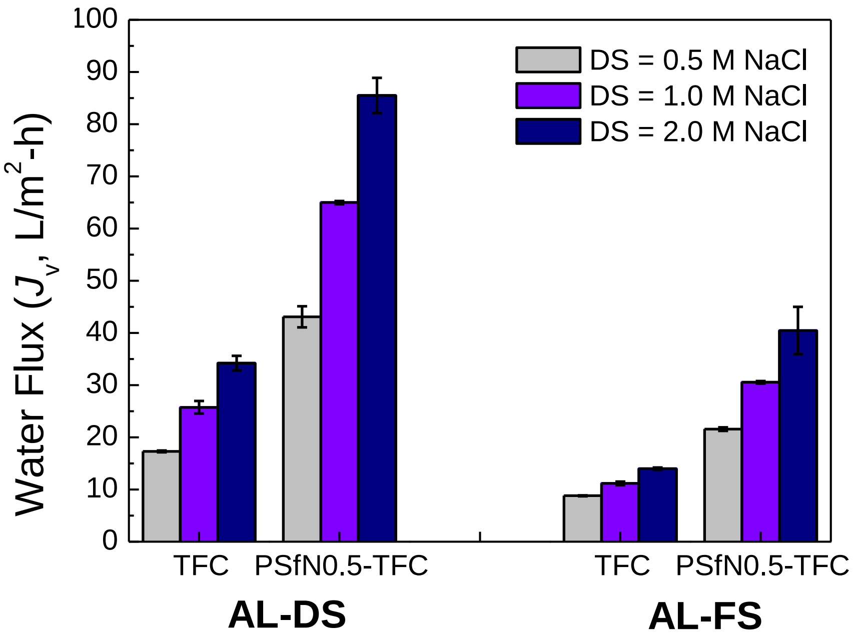
Chou, S.; Shi, L.; Wang, R.; Tang, C. Y.; Qiu, C.; Fane, A. G., Characteristics and potential applications of a novel forward osmosis hollow fiber membrane. *Desalination 2010, 261, 365-372.*

Wei, J.; Qiu, C.; Tang, C. Y.; Wang, R.; Fane, A. G., Synthesis and Characterization of Flat-sheet Thin Film Composite Forward Osmosis Membranes. *Journal of Membrane Science 2011, 372, 292-302.*

Wei, J.; Qiu, C.; Tang, C. Y.; Wang, R., Influence of Monomer Concentrations on the Performance of Polyamide-based Thin Film Composite Forward Osmosis Membrane. *Journal of Membrane Science 2011, in press*

Mixed matrix substrate for controlling ICP





FO membrane prepared on nanocomposite substrate (PSfN0.5-TFC)

Ma et al., Nanocomposite Substrates for Controlling Internal Concentration Polarization in Forward Osmosis Membranes, Journal of Membrane Science, accepted for publication.

Summary

- **FO applications**
  - **Wastewater**
  - **Seawater**
- **FO membrane performance**
  - **Membrane properties ←→ performance**
  - **High performance FO membranes**

Acknowledgements

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  - Wang Rong, Tony Fane, You Shijie, Victor Chang
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