NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE
Singapore Membrane Technology Centre
Nanyang Environment and Water Research Institute

# Pilot-scale study of pressure-retarded osmosis for osmotic power harvesting using real wastewater brine

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## PRO process and challenges

**PRO is a promising membrane-based process for osmotic power harvesting.**

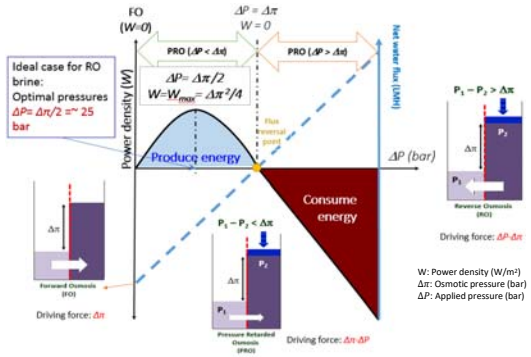



*Fig.1. Relationship of power density, net water flux and pressure in RO, FO and PRO process.*

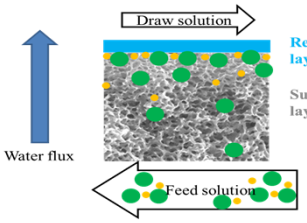
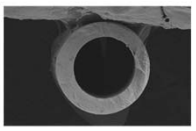



*Fig. 2. Illustration of membrane fouling in PRO membranes.*

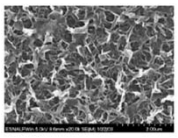
- Real wastewater brine is rich in organic and inorganic content
- Accumulation of scalants and foulants in the substrate of the membrane is expected
- The internal concentration polarization will enhance the fouling situation
- Synergetic effect between scalants and foulants will further deteriorate membrane performance

## Methods and objectives

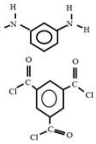
Hollow fiber substrate (phase inversion)
✚
Ultra-thin dense skin (interfacial polymerization)



Thin-film composite hollow fiber membrane



(MPD) + (TMC)



Hollow fiber membranes made from polyetherimide (PEI) were spun based on the **non-solvent induced phase separation** (NIPS) method. The polyamide layer was formed on the inner surface by **interfacial polymerization** (IP).

*Fig. 3. Schematic diagram for preparation for the PRO membrane*

2 inch PRO modules with 1000 fibers (**0.5m²**)


*Fig. 4. Captures of pilot PRO modules (left) and pilot PRO test setup (right)*

- ❖ **To explore the feasibility of in-house hollow fiber PRO membrane in PRO process with NEWater brine as feed**
- ❖ **To assess the practicability of the HF module in a pilot PRO test**

## Results and discussion

**Membrane fouling using NEWater brine as feed**

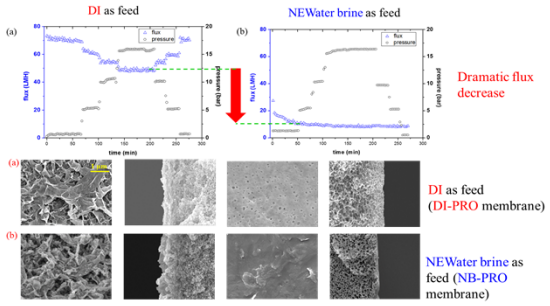
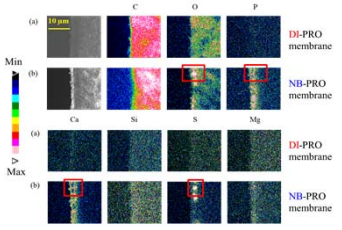



*Fig. 5 PRO performance using DI water and NEWater brine as feed (up) and SEM images of the PRO membrane after test (down)*




- The EDX mapping of cross section near inner layer of the DI-PRO membrane and NB-PRO membrane has shown a strong signal of **Ca, P, O and S** near the IP layer of the NB-PRO membrane.
- This explains the severe fouling could form complex foulants underneath the IP layer and cause a significant flux drop in PRO.

Table 1. Summary of Ca, Mg and Si concentration in different solutions

| PRO feed solution | Ca (ppm) | Mg (ppm) | $SO_4$ (ppm) | $PO_4$ (ppm) | Organic carbon (ppm) | Si (ppm) | Conductivity (us/cm) @ 25 °C | Notes |
|---|---|---|---|---|---|---|---|---|
| NB | 112.1 | 16.2 | 301.4 | 17.4 | 41.3 | 15.3 | 2520 ± 5 | Raw NEWater Brine (NB) |
| NF/P | 15.8 | 0 | 13.3 | 4.4 | 12.3 | 14.2 | 1750 ± 4 | NF permeate of NB using in-house NF module |
| NF270/P | 56.3 | 8.4 | 20.7 | 6.7 | 9.6 | 14.5 | 2240 ± 6 | NF permeate of NB using commercial NF270 |
| Tight-NF/P | 3.9 | 0 | 8.5 | 4.8 | 3.8 | 14.1 | 1432 ± 8 | NF permeate of NB using in-house tight NF module |

- The **NF pre-treatment** is effective in removing most of the multivalent ions in the NB solution and thus significantly improved the feed water quality.
- With tighter NF used for the pre-treatment, higher PRO flux was obtained.
- Low pressure NF pre-treatment is promising in the practical PRO operation when using NB as feed.

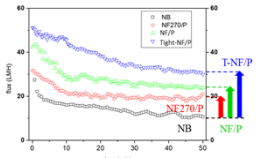



*Fig. 6. PRO performance using different feed water*

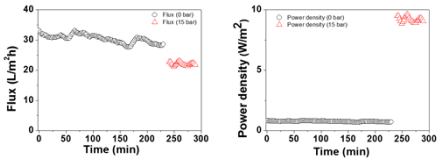



*Fig. 7 PRO test using pilot PRO setup with 2 inch PRO modules*

- NEWater brine is a **pressurized stream** (~ 5 bar).
- The pressure could be utilized to pre-treat the NB at **no additional pumping cost**.
- High power density (**8.9 W/m²**) was produced using NF-treated NB solution.

## Conclusions

- ❖ PRO fouling with NEWater brine significantly compromises power production due to Ca accumulation.
- ❖ Low pressure NF pretreatment is possible to improve the energy production in PRO by removing most of the Ca.
- ❖ Defect-free 2-inch PRO modules has been developed for pilot PRO study.
- ❖ A batch pilot PRO test to demonstrate the feasibility of pilot PRO operation where a power density of ~8.9 W/m² was produced.

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