NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Electrically assisted reverse osmosis for enhancing boron removal in one-pass SWRO desalination

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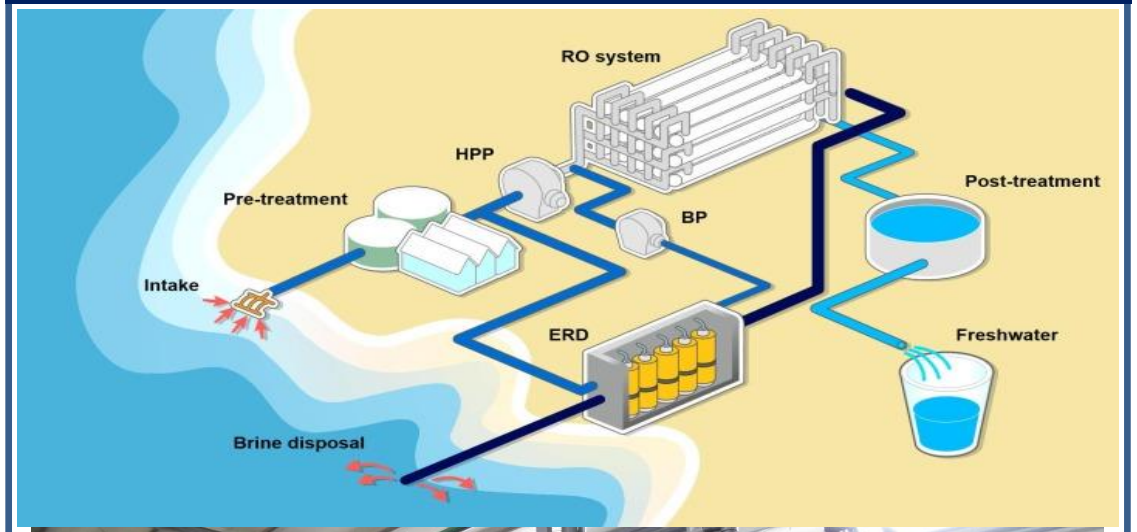
Outline

- Background
- Proposed electrically assisted reverse osmosis (EARO)
- Experiments
- Results

Seawater reverse osmosis desalination

SWRO Desalination



✓ Nearly rejects all salt ions

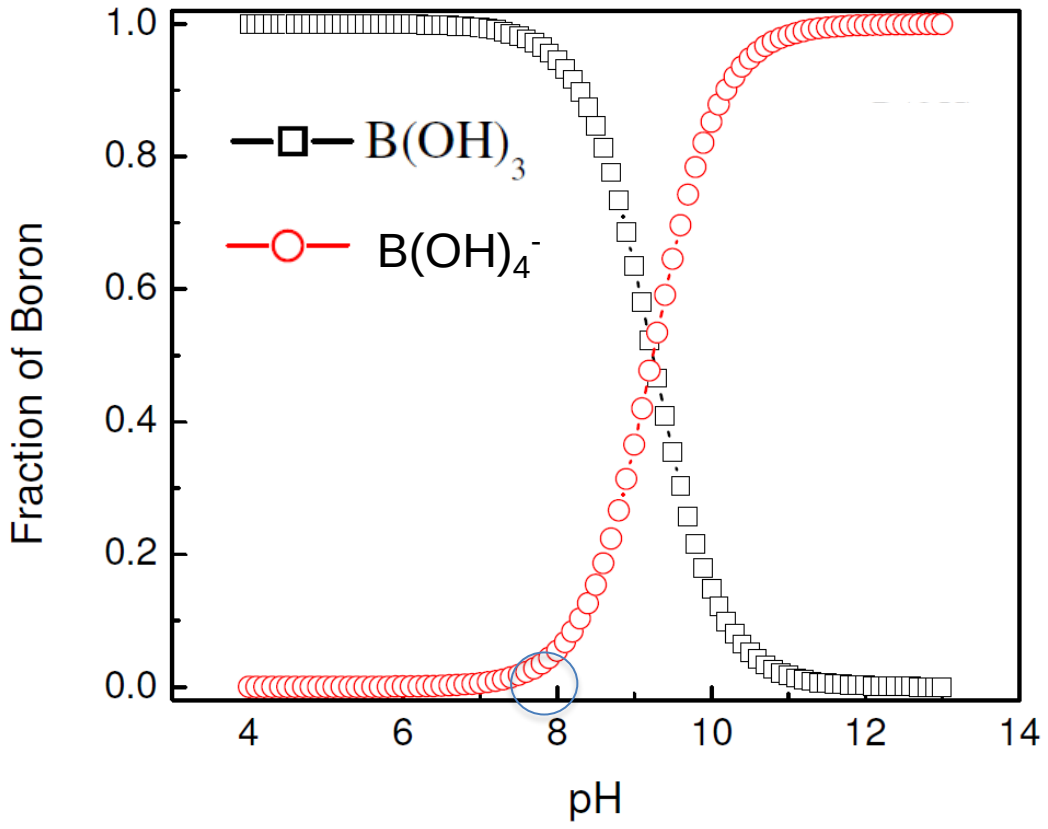
✗ Unsatisfied boron rejection

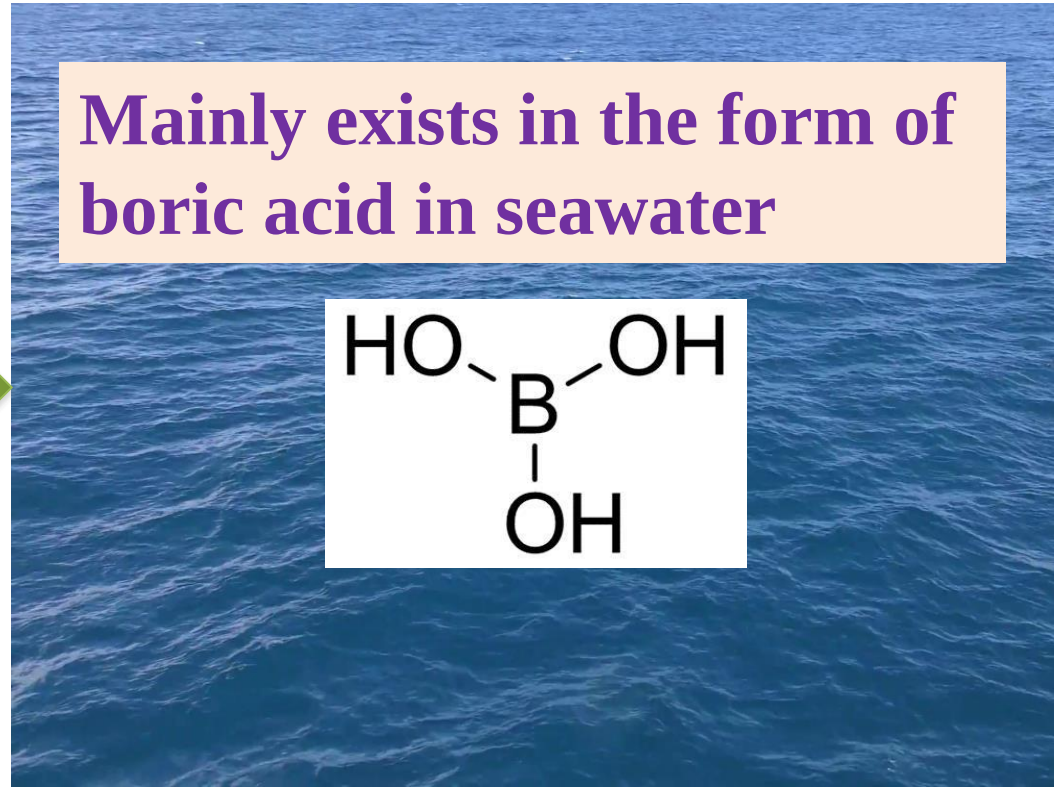
- **WHO stipulated that boron concentration in irrigation water should be lower than 0.5 ppm**

Boron properties

Average 5 ppm in seawater

Boron species as a function of pH





- Electrically neutral
- Small size (0.244–0.261 nm)

Improve boron removal in SWRO desalination

1) Modification of SWRO membranes

- Plugging
- Incorporating

functional additives → Enhance membrane selectivity

Problem: Reduce membrane water permeability

2) Post-treatment of SWRO permeate

- Second RO pass
- Ion exchange resin selective adsorption

$$B(OH)_3 + H_2O \leftrightharpoons B(OH)_4^- + H^+ \ (pKa = 9.23)$$

Larger size, negatively charged

Problem: Substantial increase in capital cost, footprint, and chemical consumption

3) Pre-treatment of feed seawater

- Elevating feed water pH

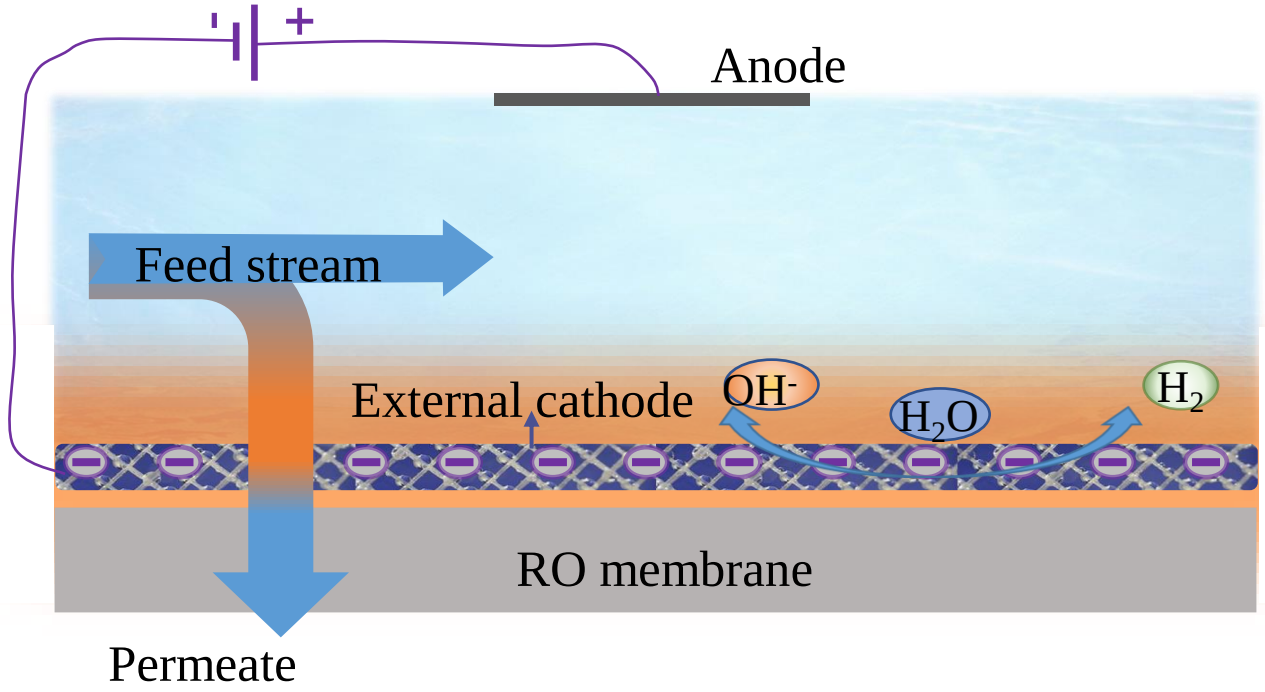
$$B(OH)_3 + H_2O \leftrightharpoons B(OH)_4^- + H^+ \ (pKa = 9.23)$$

Problem: consumes a large amount of alkali for pH adjustment

Ref: Comparison analysis of different technologies for the removal of boron from seawater: A review. 2021

Our method: electrically assisted RO (EARO)

Placing external cathode on membrane surface to elevate local pH instead of bulk feed pH



Maintain the original properties and integrity of the SWRO membrane

Cathodic reaction on membrane surface:

$$2H_2O + 2e^- \leftrightarrow H_2 + 2OH^-$$

- **Boron transport**
- **Salt transport**
- **Water flux**

Experiments

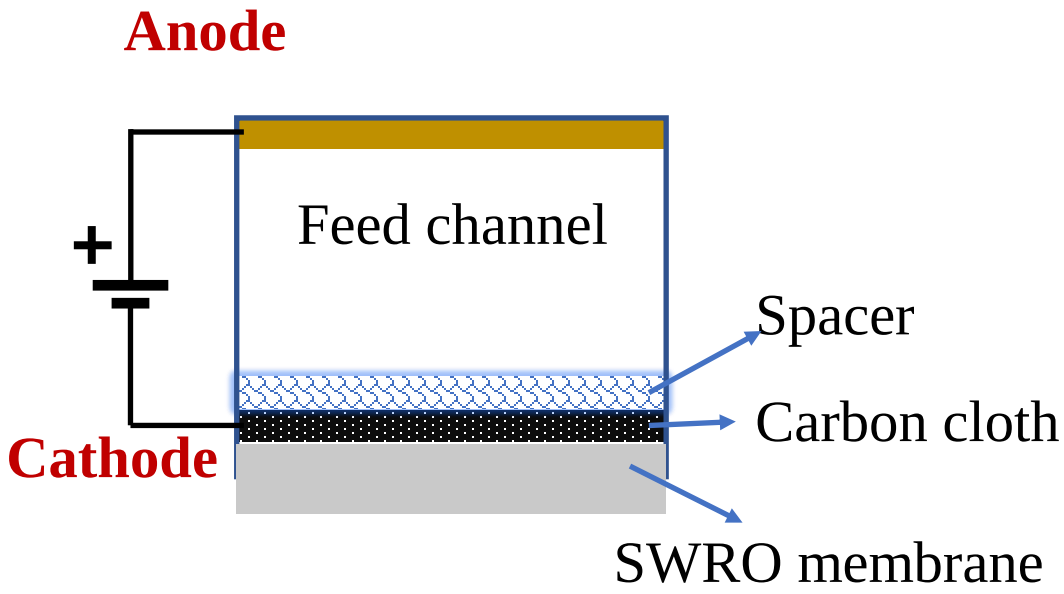
Electrodes ⇒ Integrated into feed channel

- **Cathode: Porous carbon cloth**

  Placed on the top of a commercial SWRO membrane surface in the feed channel

- **Anode: Platinum plate**

  Placed on the top of feed chamber



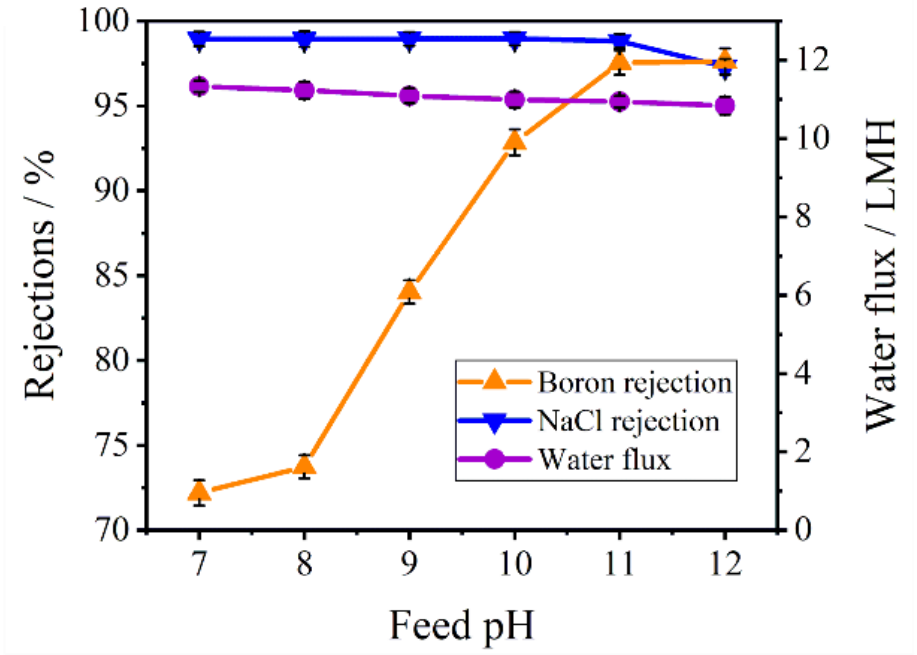
RO pressure: 600 PSI

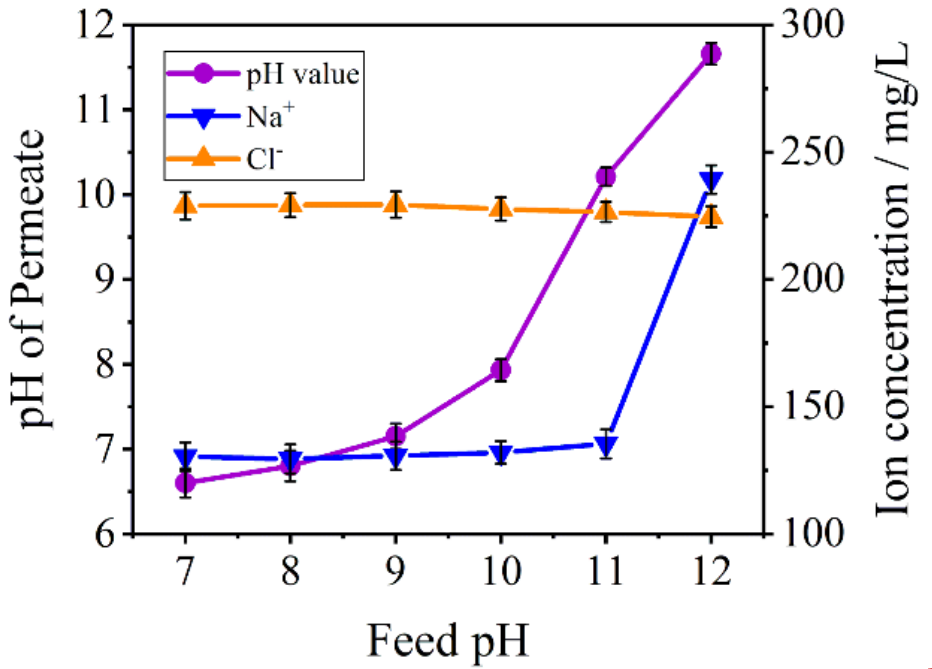
Feed water

Synthetic salt water with NaCl concentration of 35 g/L (i.e., a typical seawater salt concentration) and boron concentration of 5 mg/L

Performance of conventional RO process

pH value on the performance of conventional RO

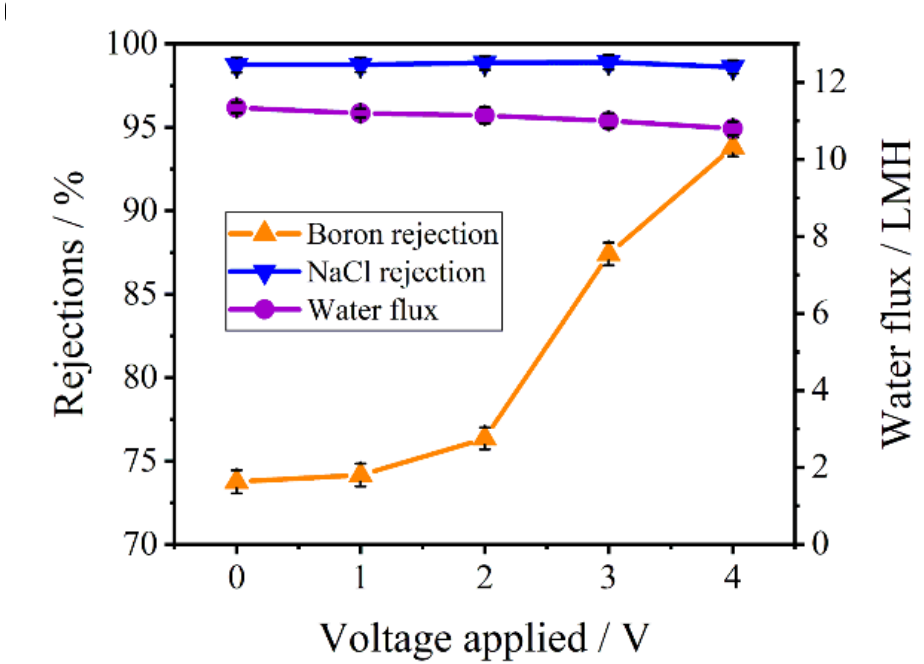


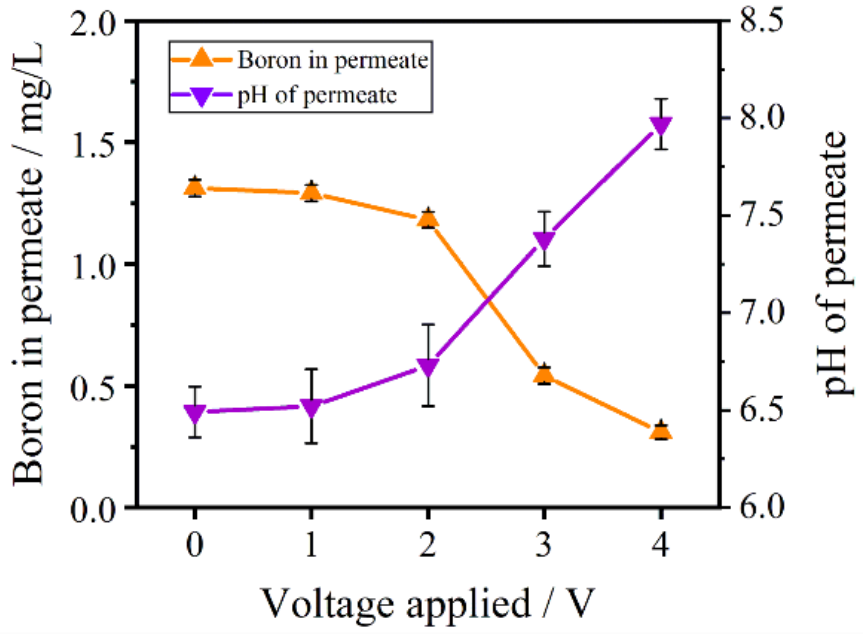


- Boron rejection increased with increasing feed pH
- Salt rejection and water flux mildly changed until pH 12

Performance of electrically assisted RO (EARO)

Applied voltage on boron and salt ion transport in EARO



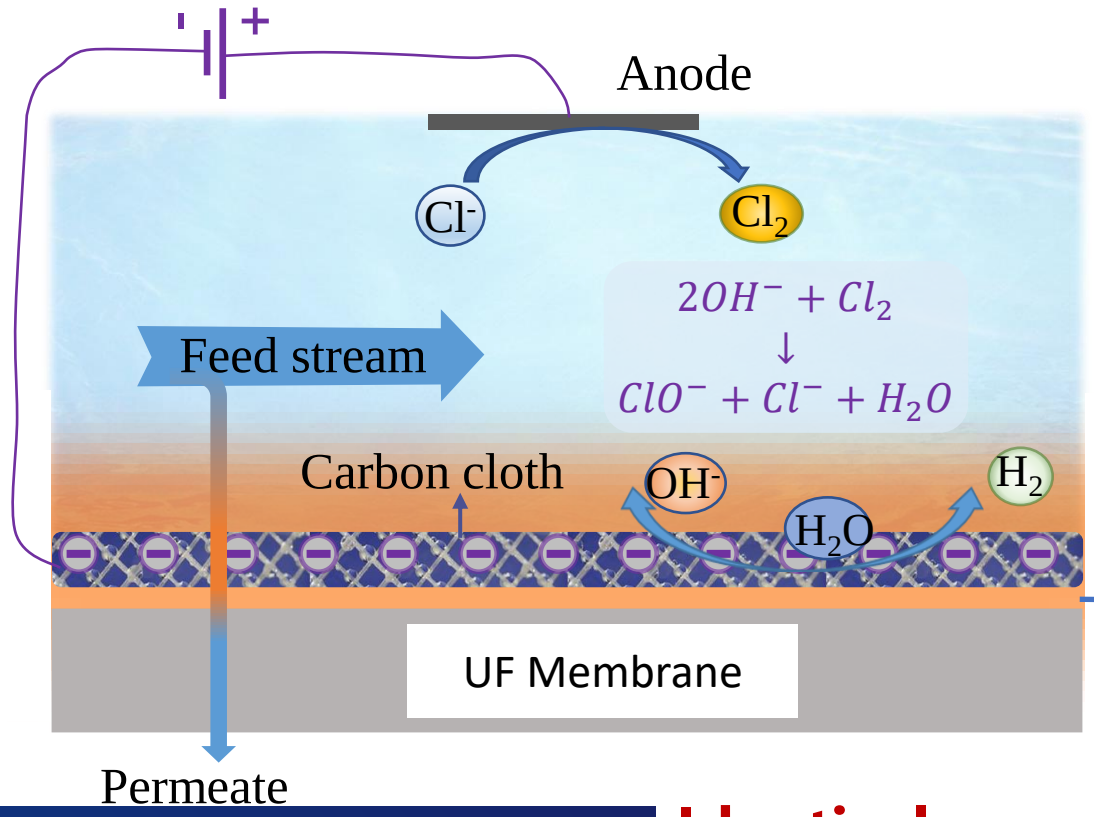


- Boron rejection significantly increased with applied voltage
- Salt rejection and water flux were nearly stable with applied voltage

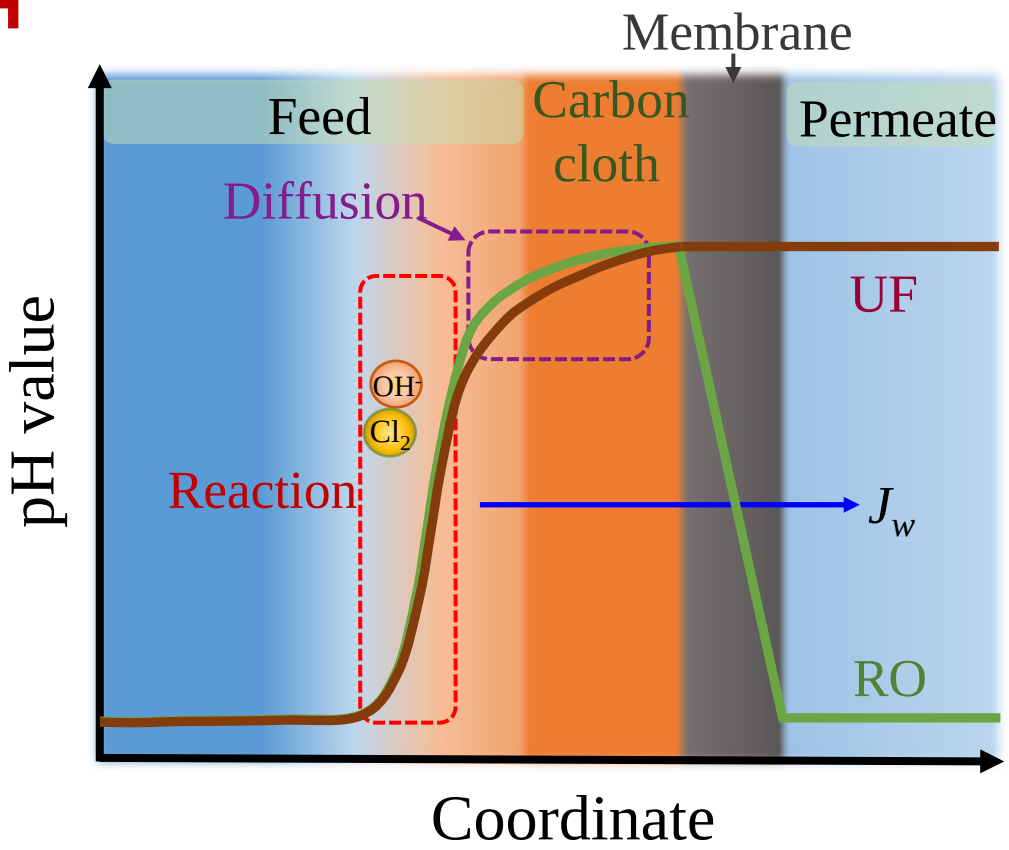
Determination of local pH in EARO

Boron transport ➢ **Enhanced local pH**

Local pH can not be measured directly



Local pH

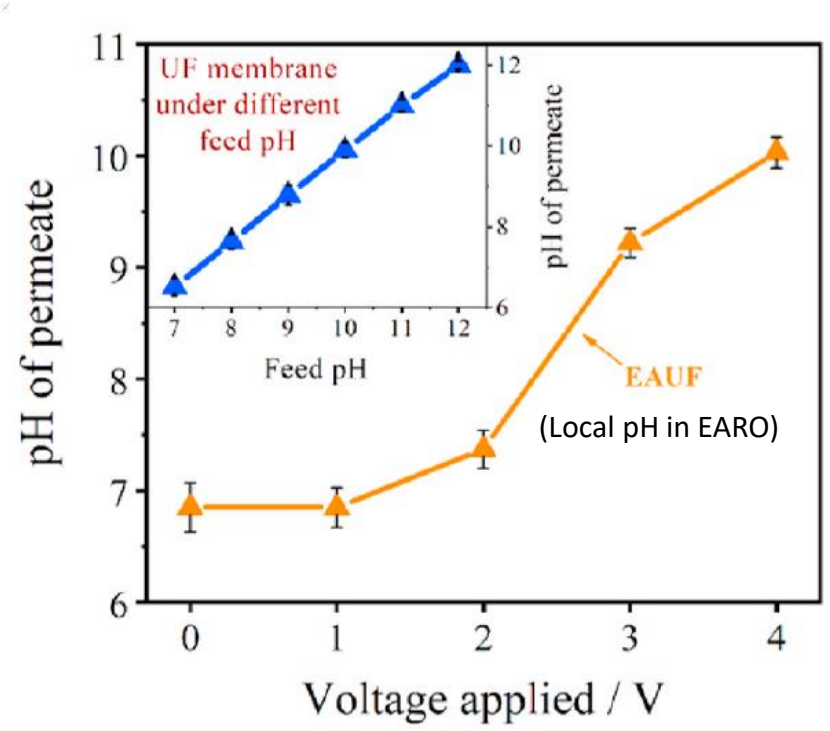


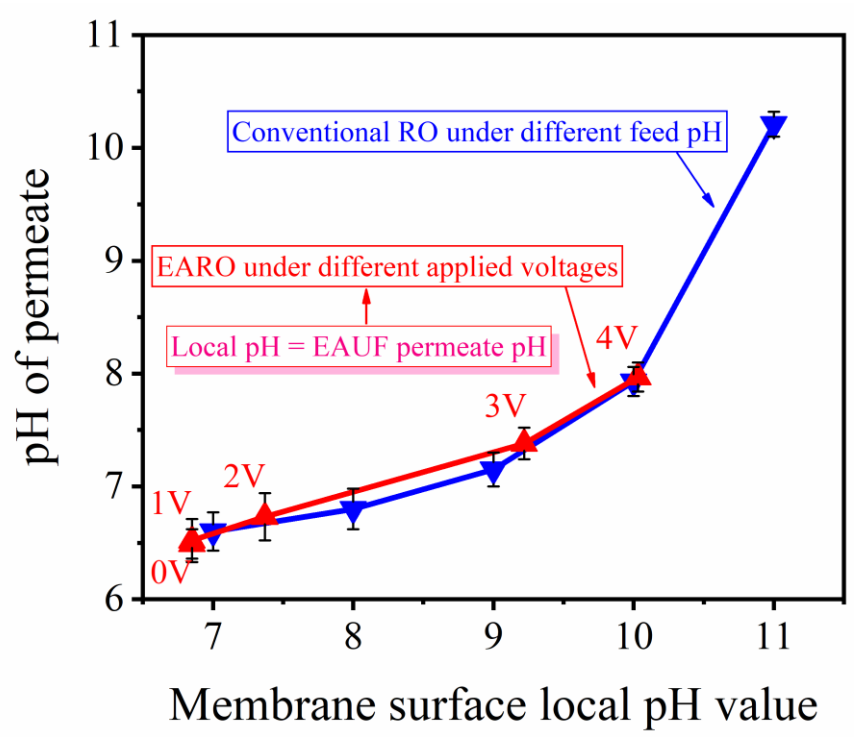
Local pH equals to the permeate pH in EAUF

Identical cross-flow velocity and water flux In EARO and EAUF

Determination of local pH in EARO

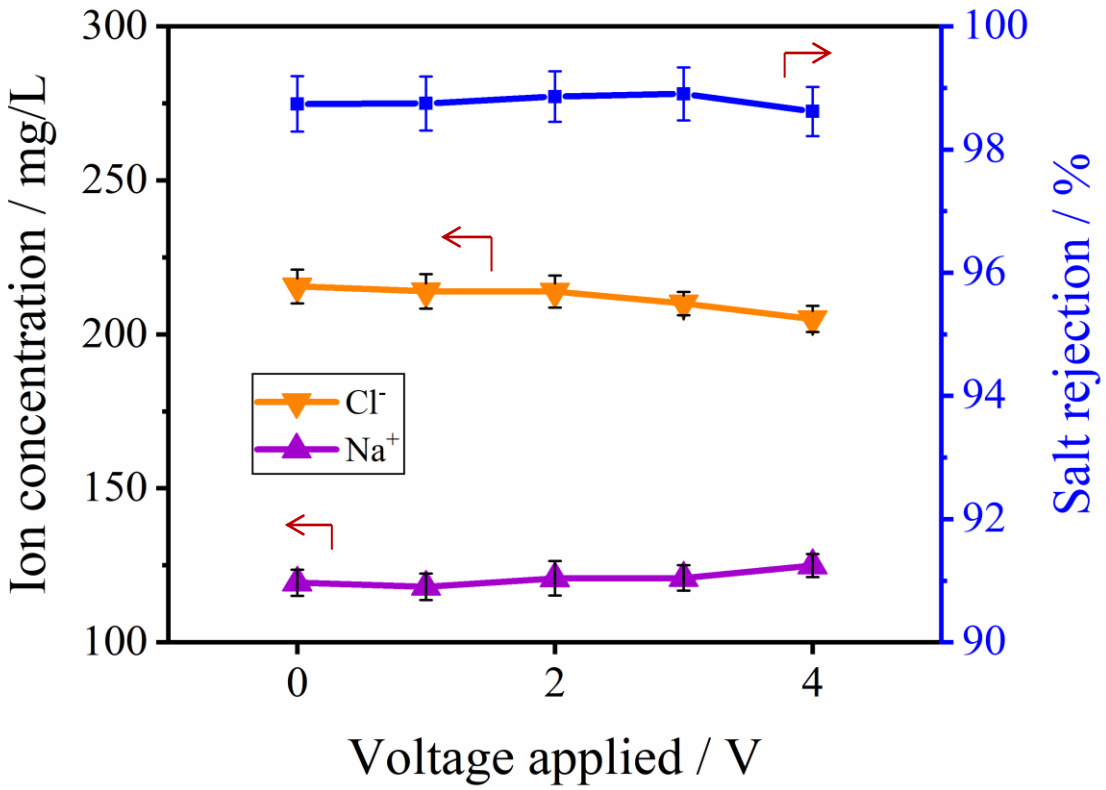
Boron transport ➢ **Enhanced local pH**

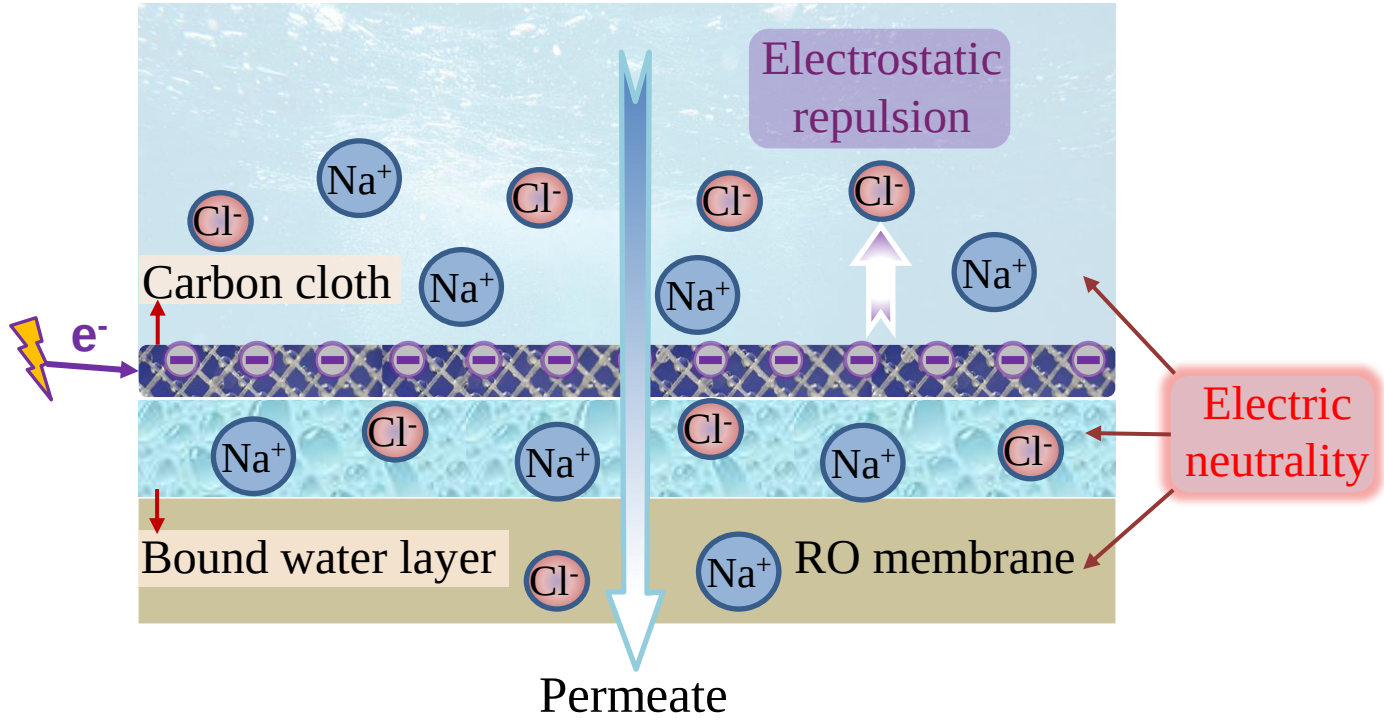




- The local pH in EARO was estimated by the permeate pH in EAUF
- The variations of permeate pH with local pH are similar between EARO and conventional RO

Salt transport in EARO

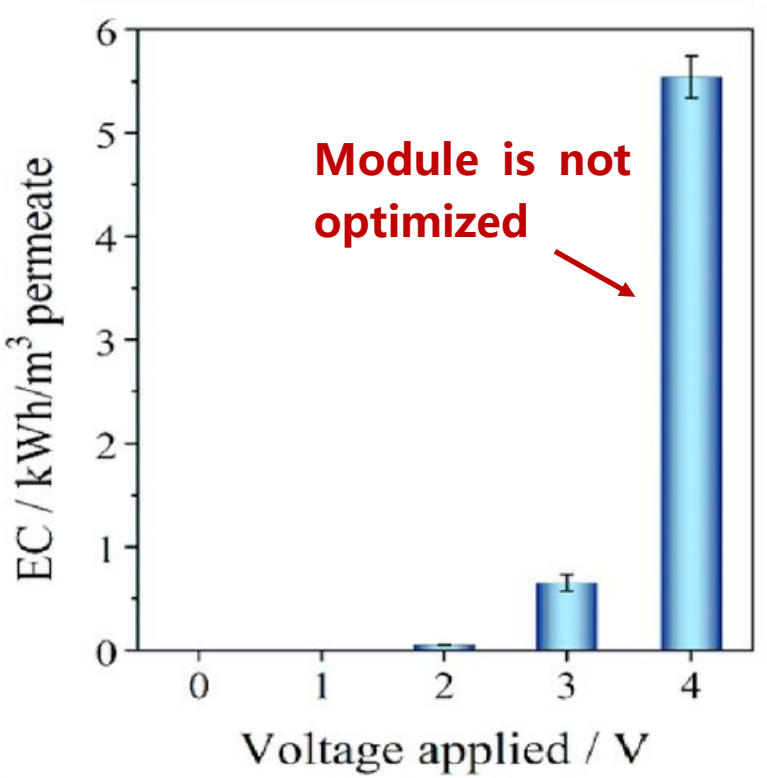




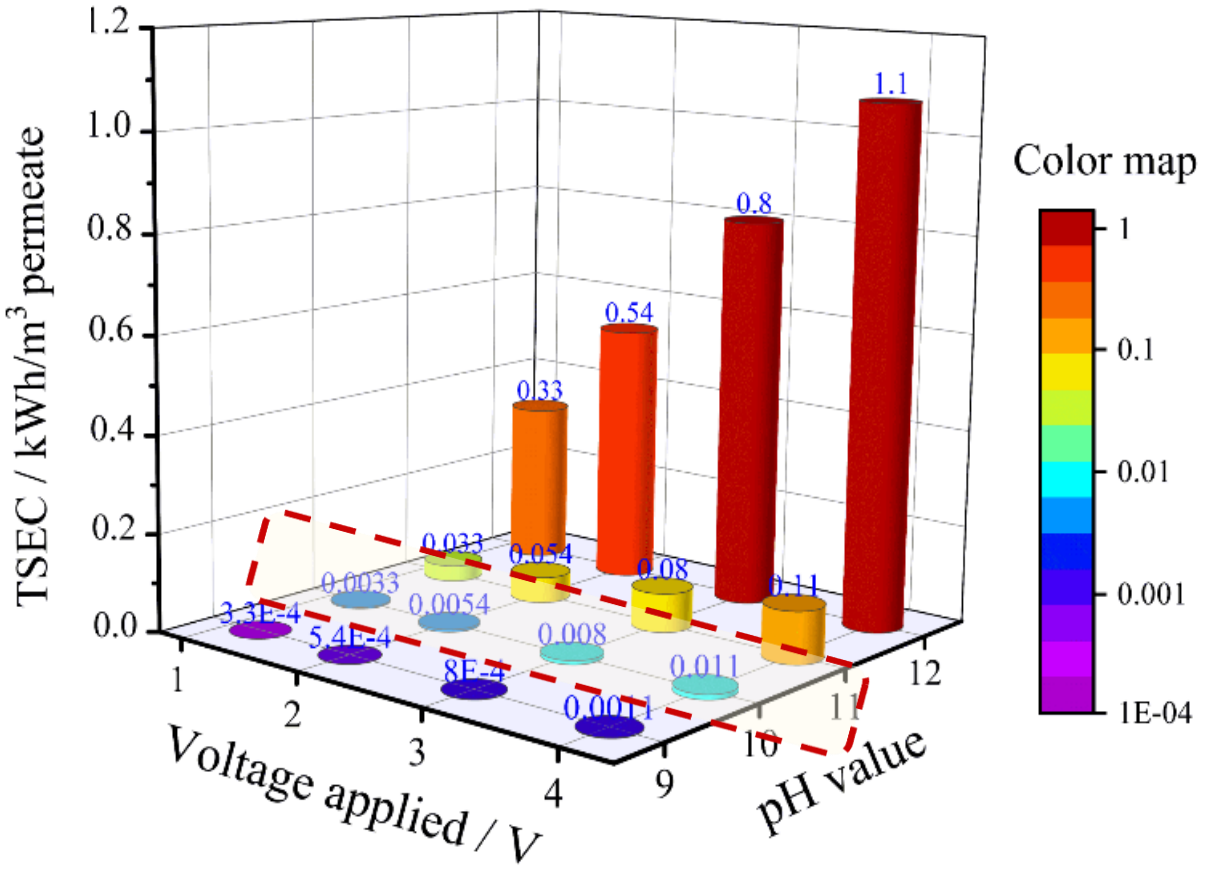
- Salt rejection is almost stable under different voltages
- Slight decrease of permeate Cl^- concentration at increasing voltages

Energy consumption of EARO for boron removal

This study



Theoretical specific energy consumption (TSEC)



New development: SEC < 0.5 kWh/m³

Conclusions

- A new electrically assisted reverse osmosis (EARO) process was developed by integrating the electrochemical process with reverse osmosis
- Boron rejection increased from ~75% to above 93% when the applied voltage increased from 0 to 4 V in EARO in one-pass SWRO process.
- Salt rejection and water flux was nearly constant under different applied voltages in EARO.
- Low energy consumption can be expected for EARO based on theoretical analysis.
- EARO is a low energy, no chemical technology for enhancing boron removal in one-pass RO desalination.
- **Future direction:**
  - to optimize the electrically conductive feed spacer and membrane module design.

Acknowledgements

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- Group members

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Thank you for your attention!

Q&A

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