New Membrane Water Treatment Technologies

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- As fresh water resources become increasingly scarce in WA, there is an increased focus on the potential to utilise the state's plentiful but brackish water sources
- Water Corporation WA is investigating two high-recovery desalination technologies, electrodialysis metathesis (EDM) and integrated forward-reverse osmosis (iFORO), that may unlock barriers to the use of brackish waters
- The technology could also be used to complement existing on-farm desalination systems, improving efficiency and providing more control over the chemistry of treated water

Conventional hydraulic pressure-driven desalination technologies, such as reverse osmosis (RO), often operate at low recovery rates due to scaling from silica and inorganic salts. These systems consume substantial energy and chemicals and generate large volumes of brine (concentrated wastewater) that are difficult and costly to dispose of. BOX 1 explains the different hydraulic pressure-driven membranes and what they are often used for.

Electrodialysis metathesis (EDM) and forward osmosis (FO) use fundamentally different mechanisms to remove salts from water (ion exchange and non-pressure-driven osmosis) that mitigate the issue of scaling, increase recovery rates and improve energy efficiency. Both technologies could be used to complement RO systems, and EDM could potentially serve as an independent water treatment option.

BOX 1. Conventional hydraulic pressure-driven membrane types

Hydraulic pressure-driven membranes act as barriers that allow the passage of water, but stop unwanted substances such as salts, organic matter, and other particles. They are made from polymer-based films, ceramics, and other materials, configured in tubular, hollow-fibre, or flat-sheet arrangements. Pressure is used to force water through these membranes, with pore size determining the level of filtration and the energy needed to push water through. (Figure 1)

- **Microfiltration (10 to 0.1 micron):** removes large contaminants such as suspended solids, oil emulsions, cells, and bacteria. Often used as a pre-treatment for reverse osmosis.
- **Ultrafiltration (0.1-0.01 micron):** removes everything microfiltration does plus proteins, viruses, and other pathogens. Often used as a pre-treatment for nanofiltration and reverse osmosis.
- **Nanofiltration (0.01-0.001 micron):** removes everything ultrafiltration does plus pesticides, herbicides, dissolved organics, most tannins, and divalent and multivalent ions (e.g. Ca^{2} , Mg^{2} , Fe^{2} , Fe3 , CO_3^{2}). Often used for water softening.
- **Reverse osmosis (0.001-0.0001 micron):** removes all contaminants including monovalent ions (e.g. Na^+, Cl^-, K^+, F^-).

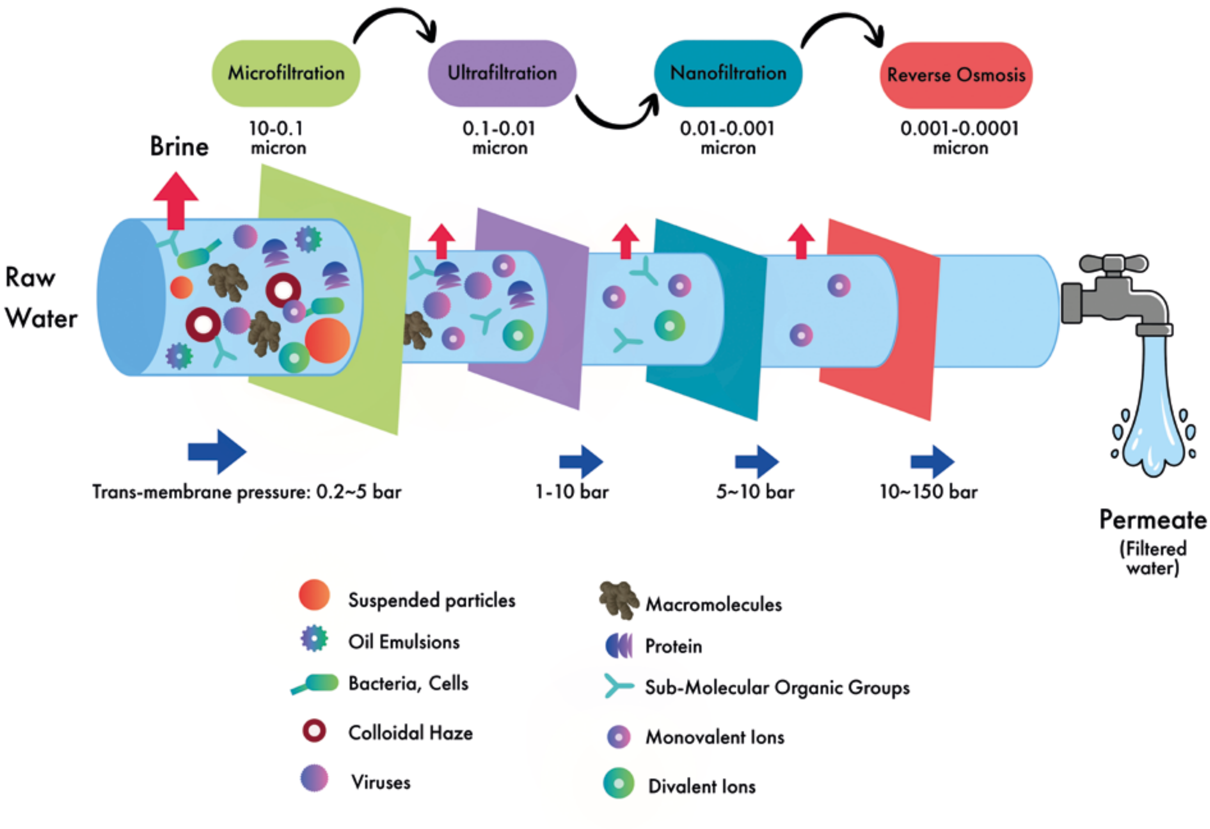

Figure 1. Hydraulic pressure-driven membrane filtration types

Electrodialysis metathesis (EDM)

Electrodialysis metathesis (EDM) is an advanced form of electrodialysis that uses ion exchange membranes and an applied electric field to selectively separate and rearrange dissolved ions. The electric field induces metathesis reactions that convert sparingly soluble salts into highly soluble forms which are separated by ion exchange membranes into distinct streams (BOX 2).

Selective ion separation allows scale-forming ions such as calcium sulfate to be isolated from one another, significantly reducing the risk of membrane fouling. This enables EDM to operate at much higher water recovery rates than RO.

Another advantage of EDM is that it can be finely tuned through voltage control to meet specific water quality needs. Instead of removing all salts, as is the case with RO, you can selectively remove and/or retain salts as needed, offering greater flexibility across varying groundwater chemistries.

EDM has reached a Technology Readiness Level (TRL) of 7 through large-scale demonstration projects in Texas and the Netherlands. Local testing under Australian groundwater chemistries is essential to confirm its performance in Australia.

TLR is a type of measurement system used to assess the maturity level of a particular technology on a scale of 1 to 9. This is a useful scale to understand when looking at new and novel technologies. Read more here: bit.ly/BA-TRL

At the Kay Bailey Hutchison Desalination Plant in Texas, RO has traditionally been used to transform brackish groundwater into fresh drinking water. The existing RO system recovers approximately 83% of the feedwater, with the remaining concentrated brine disposed of through deep-well injection. When EDM was tested at the plant, water recovery increased to as much as 90%, representing a 7% improvement over RO alone. When EDM was used as a post-RO treatment for the brine stream, total water recovery exceeded 98%, reducing the waste brine volume to less than 2%.

BOX 2. Ion exchange membranes and EDM

Ion exchange membranes selectively transport dissolved ions under the influence of an electric field while preventing the passage of ions with the opposite charge.

Cation exchange membranes allow only positively charged ions (cations) to pass, whereas anion exchange membranes allow only negatively charged ions (anions) to pass. (Figure 2)

These membranes form the basis of electrodialysis technologies, which separate salts by electrically moving ions rather than by forcing water through a membrane under pressure. (Figure 3)

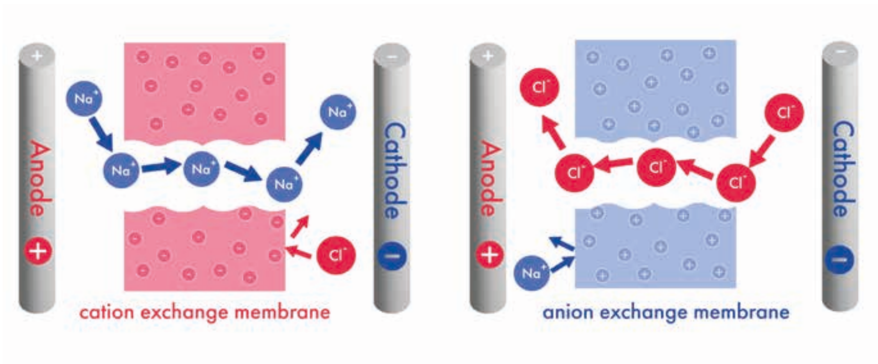

Figure 2. Close-up schematic of ion exchange membranes showing the selective permeability of a cation exchange membrane (left) and anion exchange membrane (right)

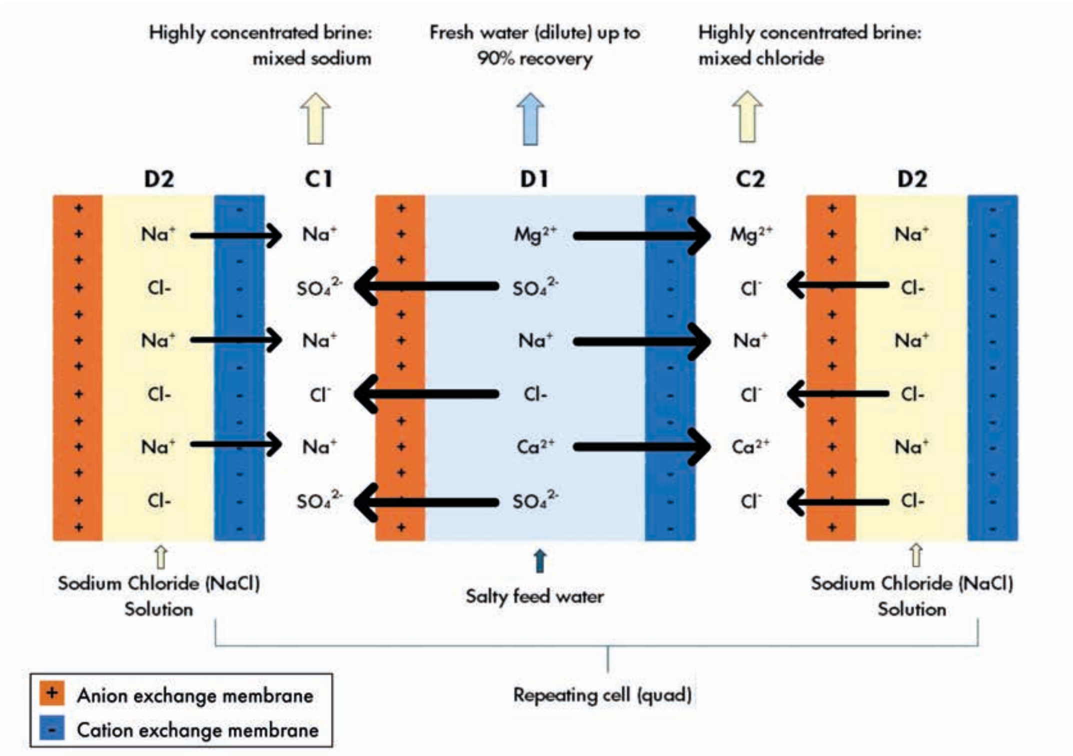

Figure 3. Schematic of the EDM system being tested by Water Corporation in WA. An electric field is applied to the salty feed water that converts sparingly soluble salts into highly soluble forms so that can be separated by the membranes: e.g. calcium sulfate ($CaSO_4$) is converted into highly soluble sodium sulfate (Na_2SO_4) and calcium chloride ($CaCl_2$).

Integrated Forward and Reverse Osmosis (iFORO)

Traditionally, RO needs elaborate pre-treatment to prevent fouling of the membrane and excessive energy consumption. In an iFORO system, forward osmosis does the pre-treatment in one energy-efficient step, removing most contaminants before they reach the RO membrane. This minimises scaling on the RO membrane, increasing its efficiency (reducing energy consumption) and reducing maintenance requirements. iFORO systems currently operating in WA are achieving recovery rates on brackish groundwater of up to 90%.

Forward osmosis uses a highly concentrated draw solution to facilitate the natural osmotic movement of water from a 'dirty' feed solution into a solution that can be efficiently processed by RO. Sodium (Na) is often used in the draw solution as it is easily removed using RO.

Unlike RO, where water is forced through a membrane under pressure, the natural movement of water across the FO membrane means there is less propensity for fouling.

Brine generated by the RO step in the process is fed back into the FO draw solution, creating a closed loop.

The process of osmosis and forward osmosis is explained in BOX 3. Figure 5 shows a schematic of the iFORO prototype developed by CSIRO and being tested by Water Corporation in WA. (Figure 6)

BOX 3. Osmosis and Forward Osmosis

Osmosis is the passive movement of water molecules across a semipermeable membrane from a region of low salt concentration to a region of high salt concentration until the same salt concentration (equilibrium) is reached on both sides of the membrane.

Salt particles can't cross the membrane, so the water must pass from one side to the other to achieve equilibrium.

In the case of forward osmosis (FO) a highly concentrated sodium (Na) draw solution is used on one side (Side B) of the membrane to encourage the passive movement of water across the membrane from Side A. (Figure 4)

A salt concentration gradient is always maintained to ensure the continual movement of water; equilibrium is never reached in the FO system, as it would cause the movement of water to stop.

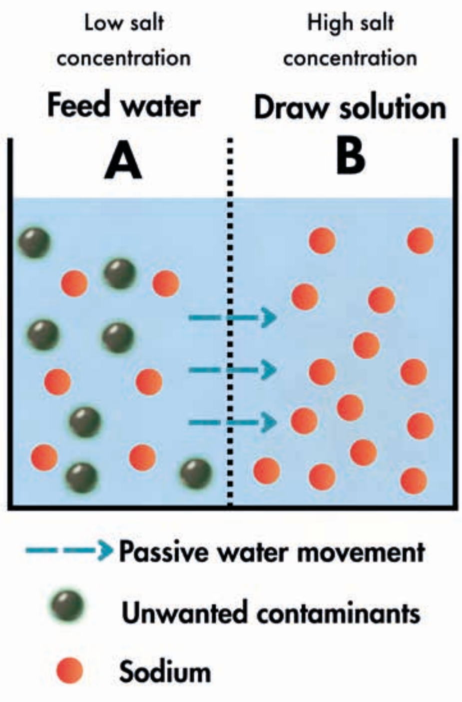

Figure 4. Diagram showing how fresh water moves across the semipermeable membrane from the feed water stream into the concentrated sodium draw solution through passive osmosis.

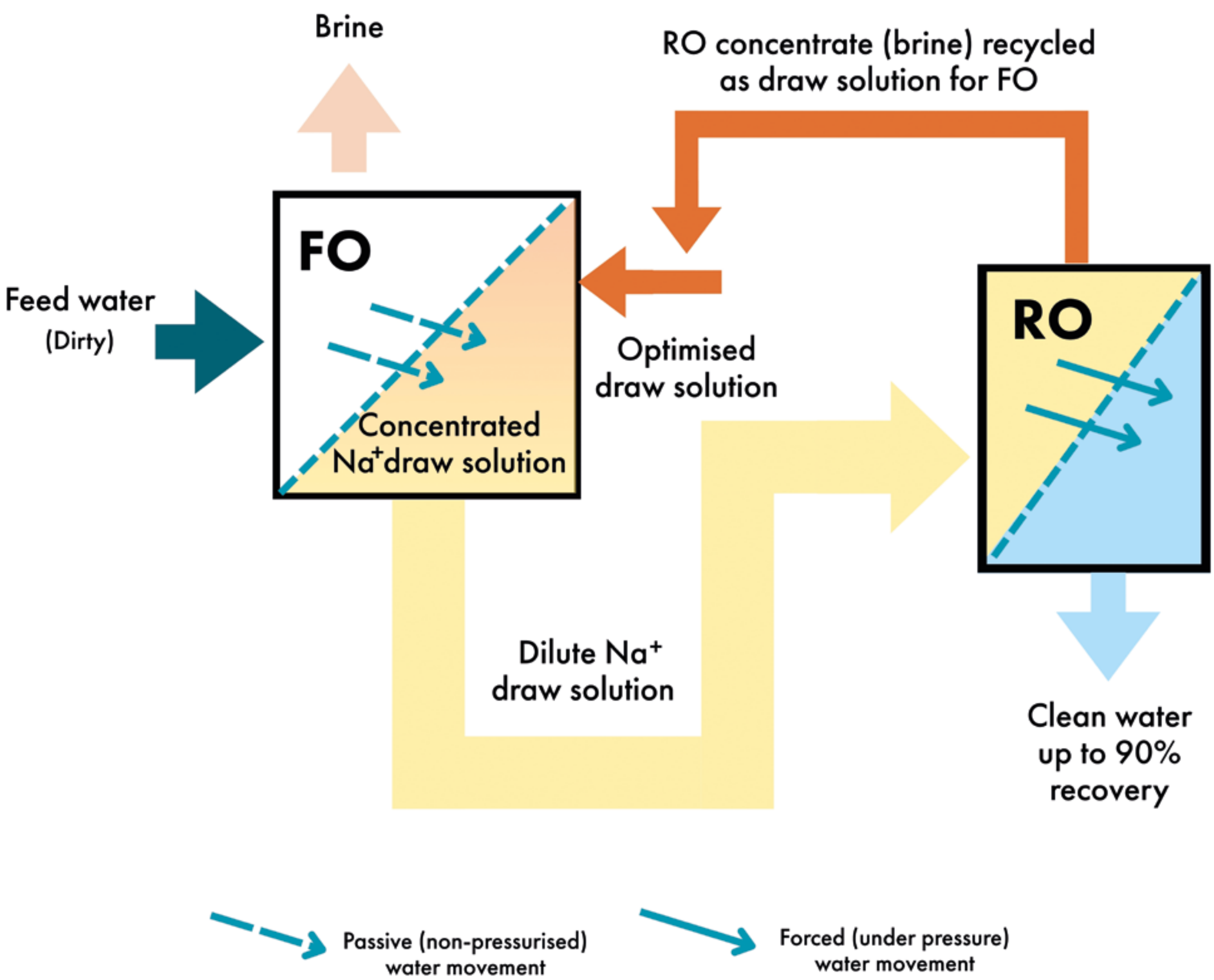

Figure 5. Schematic showing the integrated forward osmosis (FO) reverse osmosis (RO) process

Figure 6. Water Corporations iFORO prototype fits in a 20-foot shipping container and can treat up to 10,000 litres of per day. Courtesy CSIRO.

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