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a step in the right direction

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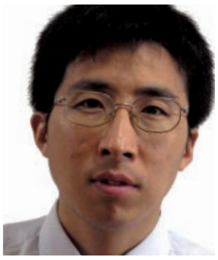
Worth their salt

Nanotech membranes show promise for a breakthrough in electrodialysis desalination efficiencies, explain **Bradley Ladewig**, **Chalida Klaysom**, **Lianzhou Wang** and **Max Lu**



GLOBAL demand for potable water is growing, due to increasing population, industrial consumption and higher levels of affluence leading to increased *per capita* consumption. At the same time, its supply is becoming increasingly more difficult due to rainfall variability. This has had some notable impacts in areas such as south east Queensland, Australia, where state and federal governments have spent A$2.4b ($1.6b) on the Western Corridor Recycled Water Project to provide 232m l/d of recycled water to power stations, industry, and ultimately residential customers. This project is the largest recycled water project in Australia and the third largest in the world, and has been delivered by five alliances comprising 16 of the world's leading EPCM companies, including Thiess, WorleyParsons, Connel Wagner, Hatch and GHD.

Clearly, demand for new sources of potable water is running high. In some areas, it's possible to build new dams, however in many areas of the developed world most good sites for dams have already been used. Environmental pressure groups are also fairly strongly opposed to the construction of new dams.

For this reason significant attention has been devoted to desalination of saline water for the production of potable water.

desalination

Desalination of seawater is already widely employed in the Middle East for fresh water supply. This industry has developed steadily since the 1960s, mostly using thermal distillation technology owing to the plentiful and cheap supply of oil and gas in the region. Newer installations, however, use reverse osmosis, which has significantly lower energy consumption (around 4 kWh/kl). The scale of modern reverse osmosis plants is remarkable – the Ashkelon plant in Israel (see Figure 1) is the world's largest of its type, and has a production capacity of 330m l/d.

Figure 1: The scale of modern RO plants, such as the Ashkelon plant, Israel is remarkable (photo courtesy of Veolia Photo Library, R Mas)

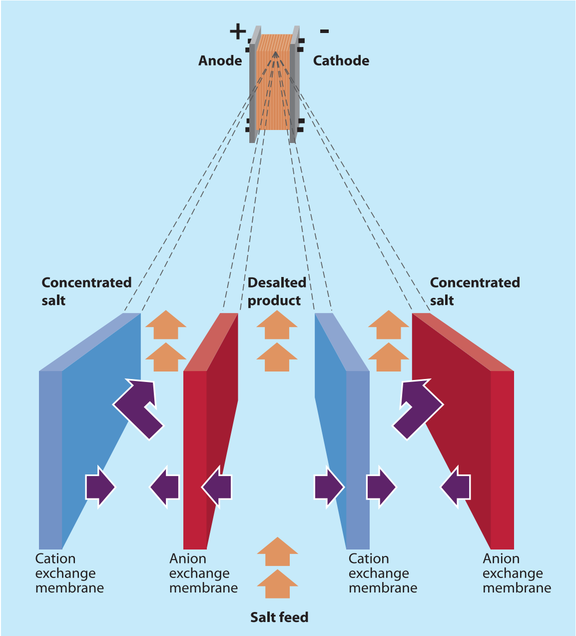


Figure 2: Electrodialysis uses ion selective membranes and an electric field to separate ions from a saline solution

Despite the maturity of reverse osmosis as a desalination technology, and the significant gains made in reducing the energy consumption, the unit production costs for potable water remains very high for most countries.

electrodialysis

In the meantime, there have been some alternative technologies for desalination with lower energy consumption being developed, such as:

- electrodialysis;
- membrane distillation;
- solar desalination; and
- capacitive deionisation.

Electrodialysis uses ion selective membranes and an electric field to separate ions from a saline solution (see Figure 2).

This is a fundamental difference to reverse osmosis, which uses water-permeable membranes. In electrodialysis, the salt ions (the minority component) are removed through the membrane from the feed solution, whereas in reverse osmosis the water molecules (the majority component) are forced through the membrane to the permeate side.

Even though electrodialysis removes the minority component from the feed solution, it still requires significant energy. Owing to the fact that the current passing through the cell is roughly proportional to the quantity of the ions being removed, electrodialysis is a very expensive way to desalinate seawater (which has approximately 35 g of salt per litre). It is, however, a viable option for the desalination of brackish (ie semi-salty) water, and may see more applications in hybridised systems with reverse osmosis, as well as in the treatment of highly saline solutions such as brine.

A prospective application of electrodialysis membrane technology in Australia is for the treatment of coal seam gas water, which is produced during the dewatering or draining of coal seams. Currently, significant quantities of such water is diverted to evaporation ponds. Moreover, with the expected massive expansion of the coal seam gas industry in Queensland, it's predicted that there will be up to 220m l/d produced, far more than can be disposed of in this way. Although the water can be treated using conventional reverse osmosis plants (and demonstration units have already been successfully trialed), the product water is of a much higher quality than is required for, say, agricultural uses. The energy consumption (and hence cost) is also too high for this industry, thus hindering the adoption of the technology. Electrodialysis, with its ability to precisely control the quantity of ions removed from the solution, is an attractive alternative to reverse osmosis in this application.

limitations

The major impediments to more widespread adoption of electrodialysis as a desalination technology have material limitations. The ion-selective membranes must possess a very specific set of characteristics, namely a high ionic conductivity, high selectivity for cations over anions (for the cation exchange membrane, and vice versa for the anion exchange membrane), high anti-fouling performance and good mechanical properties. If the ionic conductivity is not high enough, there is a greater resistance to the flow of ions through the membrane, leading to a higher power consumption. Similarly, if the membrane does not possess good mechanical barrier properties, there may be crossover of solution from the feed to the product chambers.

In our centre we are developing a new suite of electrodialysis membranes using our expertise in functional nanomaterials and polymer nanocomposites. The ability to significantly modify the properties of polymer materials – for example limiting the mobility of the polymer chains by incorporating inorganic nanoparticles to increase thermal stability – has been known for some time, and is indeed widely used in consumer and industrial products ranging from tennis racquets to aeroplane components.

However, the final composite product properties depend on a large number of variables, with the key ones being the size, distribution and surface chemistry of the nanoparticles. We have been focussing on the production of titanium dioxide nanoparticles with different sizes and surface chemistries, and mixing these or surface coating them onto ion-conducting polymer membranes such as sulphonated polyethersulphone. The polymer membrane itself may also have quite a complex composition, and it is not uncommon to combine two or more polymers in a solvent with the nanoparticles and then cast these onto a glass substrate to form a free-standing membrane. Figure 3 pictures the nanocomposite membranes – approximately 80 µm thick, with smooth external surfaces and good structural integrity.

The key materials properties that we test for are ionic conductivity, ion exchange capacity, and resistivity. Of course the ultimate test of a new membrane's suitability is its performance in an actual electrodialysis cell, and we have constructed three- and five-compartment test units for this purpose (see Figure 4a, 4b).

Testing is at a preliminary stage, and has demonstrated that the novel nanocomposite membranes can operate at least as effectively as commercial ion exchange membranes.

It is envisaged that with further development, and optimisation in particular, the nanocomposite membranes will display superior performance.

Ultimately, the commercial viability of these membranes will depend on them having good ion transport properties, long-term stability and resistance to fouling, and their ability to be manufactured at a competitive price. Fortunately, the polymer precursors and inorganic nanoparticles used are all inexpensive. **tce**

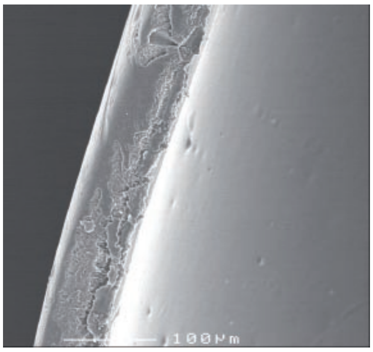


Figure 3: SEM image of a sulphonated polyethersulphone membrane produced by spin-coating. The membrane has a smooth, non-porous surface and is approximately 80 µm thick

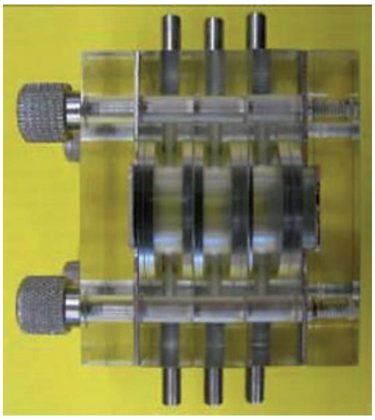


Figure 4a: Top view of the electrodialysis cell, showing the three compartments, inlet and outlet connections and compression screws for closing the cell

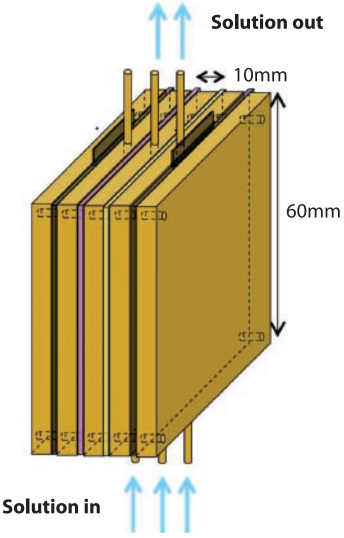


Figure 4b: Schematic representation of the three-compartment electrodialysis cell

acknowledgements

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further reading

1. Wester Corridor Recycled Water Project, www.westerncorridor.com.au
2. Xu, TW, "Ion exchange membranes: State of their development and perspective", *J Membr Sci*, 263 (1–2), 1 (2005)

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