Add salt as required: the recipe for fresh water

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Using desalination to slake the world's thirst has been an uphill struggle, but now we're learning to go with the flow

Switching direction could mean an end to water shortages (Image: JOSE LUIS ROCA/AFP/Getty)

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STROLLING along Williamsons beach, a quiet strip of sand about 100 kilometres south -east of Melbourne, Australia, you would never guess that a monster lurks just behind the dunes. Nestled at the bottom of a 27-metre-deep pit is a 500-tonne mechanical giant that is about to begin burrowing under the beach and out to sea. In its wake the machine will leave a 4-metre-wide, 1.5-kilometre-long tunnel, the inlet for one of the world's largest plants to turn seawater into drinking water.

Australia is turning to desalination as fresh water in many parts of the country runs short following years of drought. It is not alone. Many countries are eyeing the oceans as a potential source of drinking water as populations grow and rainfall patterns change. Even the relatively rain-drenched UK now has its first large-scale desalination plant, opened earlier this year on the river Thames in east London.

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Today's desalination plants are unlikely to solve our looming water crisis, however. That's because they have their own unquenchable thirst- for energy. It's needed to drive reverse osmosis (RO), the process in which salty water is forced at high pressure through a membrane that lets water molecules through but blocks the salt. But now a number of researchers and start-up companies think they have a more energy-efficient alternative, and it works by turning RO desalination on its head.

Any breakthrough would come not a moment too soon. A 2006 UN report estimates that by 2025, 2 out of 3 people could be living under conditions of water stress. Even the US may not be immune: the country is guzzling groundwater around 25 per cent faster than it can be replenished.

Modern RO desalination plants, like the one being built outside Melbourne by water treatment company Suez Environnement, use a fraction of the energy required by the original facilities of this type, constructed in the 1960s. Still, the Melbourne plant will consume at least 90 megawatts of electrical power- roughly the peak output of 20 large off-shore wind turbines- to produce 150 billion litres of water per year. That is because RO is an inherently energy-intensive process: left to its own

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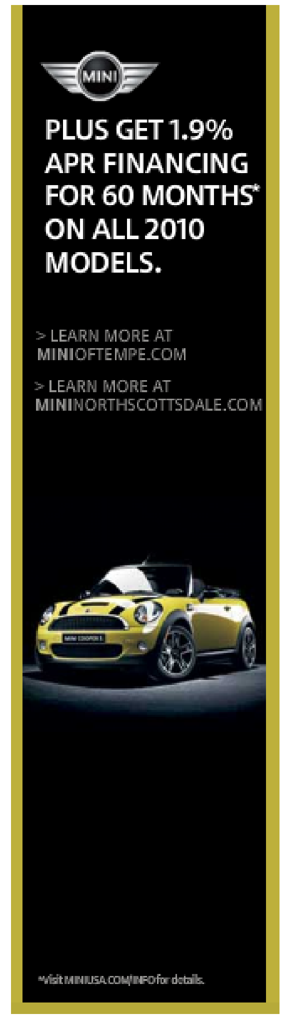

devices, water flows from a dilute solution into a salty one, whereas RO forces water to do the opposite.

Quick draw

So instead of fighting this energy gradient, why not try to harness it? That's the thinking behind the experimental "forward osmosis" plants that are starting to appear. Water can be sucked effortlessly out of seawater if you offer it a more concentrated "draw solution" to flow into. At first sight that might not appear to achieve anything, but if you are clever about what you use in the draw solution, you can get pure water out at the end.

One of the first companies to harness the power of forward osmosis is Hydration Technology Innovations (HTI), based in Albany, Oregon. In 2004 it released the X-pack, a portable water filter that incorporates a forward osmosis membrane into a small sealed plastic packet. Inside the packet is a powder containing sugar and flavourings, which acts as a seed for the draw solution. "It can be thrown into a muddy puddle and the sugar powder will draw the water molecules through the membrane to create a drink," says Walt Schultz, HTI's chief executive.

Many US soldiers now carry these packs, which can also be chucked over the side of a boat to pull a sweet drink out of the sea. The packs have also been supplied in relief aid following disasters such as the Haiti earthquake this year. But the X-pack is not going to solve the world's water crisis. "Our hydration products are intended for emergency use," says Schultz. "It is a relatively expensive way of producing a clean drink."

In the same year that HTI launched the X-pack, a team at Yale University hit on an idea that took the concept a step forward. Menachem Elimelech, Jeffrey McCutcheon and Robert McGinnis decided to use a draw solution based on ammonium bicarbonate (Desalination, vol 174, p 1). Just as HTI's sugary powder does, the ammonium and bicarbonate ions can pull water through the membrane. If you then heat the solution to around 40 °C, ammonia and carbon dioxide are given off, leaving behind pure water. The gases can be captured and reused, and the team says its method could produce fresh water while using only 20 per cent of the energy of today's desalination plants. That figure assumes, however, that waste heat from power stations is available to drive off the gases, which will limit where such plants can be sited.

> Forward osmosis could produce fresh water while using only 20 per cent of the energy of today's desalination plants.

Another challenge is finding a suitable membrane- one permeable to water but impermeable to salts. "It is the main hurdle for the forward osmosis industry," says Tom Pankratz, editor of the *Water Desalination Report* newsletter, based in Houston, Texas. The membrane needs to be as thin as possible to keep the salt water close to the draw solution and so maintain a high osmotic pressure, but robust enough to cope with the flow of water that results.

HTI has developed a cellulose-based membrane for its hydration packs and other products. However, this membrane cannot withstand the alkalinity of Elimelech's ammonium bicarbonate solution. Conventional RO membranes are also unsuitable. These structures need a strong "support layer" to reinforce the membrane against the high pressures of RO, making them too thick for forward osmosis.

Nevertheless, Elimelech and colleagues realised that taking away the thick support layer could leave you with a workable forward osmosis membrane. By experimenting with different polymer solutions, the team came up with a recipe for fabricating a membrane with a replacement support layer, which is thin yet strong and porous. In tests, the new membrane was shown to have nine times the throughput of a conventional RO membrane while keeping out over 97 per cent of the salt

(*Environmental Science and Technology*, vol 44, p 3812). The tests were done on a "hand-made lab version" of the new membrane, and "the performance should become even better if the membrane is produced on an industrial scale", Elimelech claims.

McGinnis now works for Oasys, a company based in Cambridge, Massachusetts, which is testing the new membrane and other potential candidates with ammonium bicarbonate as the draw solution. By the middle of next year Oasys hopes to have built a small demonstration plant. "The companies we are working with have waste heat which we can use in the process," says Oasys spokeswoman Lisa Sorgini.

Elimelech's membrane is not the only one undergoing trials. Wang Rong, deputy director of the Singapore Membrane Technology Centre at Nanyang Technological University in Singapore, and her team have recently developed a membrane consisting of tiny tubular fibres which can be used with ammonium bicarbonate as the draw solution (*Journal of Membrane Science*, vol 355, p 158). Salt water passes down the centre of the fibres while the draw solution swills around the outside. Wang says this type of membrane has the potential to reduce the energy used for seawater desalination by at least 30 per cent. Tony Fane, director of the centre, says that their advantage over flat sheet membranes is that it should be easy to produce modules containing thousands of fibres, which can then be assembled as required in a large-scale desalination set-up.

Meanwhile, a UK company called Modern Water, based in Guildford, Surrey, claims to have cracked the membrane problem already and to be successfully deploying forward osmosis to desalinate water, using around 30 per cent less energy than conventional desalination. Instead of ammonium bicarbonate, Modern Water uses a proprietary salt, the name of which the company won't divulge, to suck the water through their membrane. Having used forward osmosis to dilute the draw solution, it then extracts the water by reverse osmosis.

Smashing success

Modern Water's trick is that the molecules used in the draw solution are much larger than the sodium and chloride ions that have to be held back in conventional RO. That means the RO membrane can have larger pores than one to be used with seawater, so less energy is needed to force the water through. Overall, the technique requires much less energy than conventional desalination "because the forward osmosis process has already done much of the hard work", says Adel Sharif of the University of Surrey in Guildford, one of the company's founders. Modern Water says the technology is already in use at a pilot plant in Gibraltar and at a full-scale plant in Oman.

So is forward osmosis the answer to our water needs? For all its potential, there are still hurdles to overcome. Tzahi Cath, a water purification engineer at the Colorado School of Mines in Golden, says Elimelech's concept is sound, but he isn't convinced that waste heat to drive off the ammonium bicarbonate can be obtained cheaply enough to make the process economic. "Low-grade heat is not necessarily available where you need it, and when waste becomes a resource it carries a price tag," he says. The cost of the membranes may also be prohibitive, says Mark Shannon, who directs research into desalination materials at the University of Illinois at Urbana-Champaign. "The water flux in forward osmosis is low, so a lot of membrane is required," he says.

However, both he and Cath see great potential for forward osmosis in recycling waste water, something Oasys is investigating. Being less salty than seawater, waste water yields a much higher water flux because the osmotic gradient is higher, says Shannon.

For the same reason, forward osmosis may also turn out to be ideal for desalinating brackish water, such as deep groundwater and estuary water. Deep groundwater is plentiful. "Underlying almost every continent are large sources of brackish water," Shannon says. "Forward osmosis could be a smashing success."

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