BLUE ENERGY

Researchers set out to prove there's power in osmosis

The Statkraft prototype osmosis power plant in Tofte, Hurum, Norway, which was the first osmotic power plant in the world

Photo: Bjoertvedt

Osmotic power is a frustrating concept – easy to describe in theory but not so easy to capture in practice. Are key enabling technologies inching any closer to commercial development? *Mark Rowe* reports from Bristol and *Ed Zwirn* from New York.

In principle, the technology of osmotic power, known widely as 'blue energy', has a lot going for it. Unlike wind or sunlight, its electricity generating technique of mixing freshwater and saltwater at the mouths of estuaries is constant, with electrically charged salt ions moving from salty seawater to fresh river water.

Cost-effective energy achieved at scale by installing semi-permeable membranes in these sites – found around the world – is the prize. But a commercially and technically successful system has so far proved elusive. Norway's Statkraft developed a prototype facility near Oslo in 2009, but pulled out in 2013, saying that in current market conditions: 'it could not make the technology efficient enough to achieve energy production costs on a par with competing technologies.'

In Canada, Hydro-Québec also halted research on osmotic power in 2016. 'At this time, it's not a type of energy that we want to pursue – there are more mature and competitive technologies out there, such as hydro, solar and wind power,' spokesman Jonathan Côté told *Energy World*. Yet research goes on and scientists continue to make advances that may deliver osmosis to a power industry always looking for the next viable renewable system.

Research frontier

One such project is at Rutgers University, in New Jersey, which has sought to create a scalable system. The team's recent experiments with integrating single boron-nitride nanotube (BNNT) pores into membranes have demonstrated osmotic powers that could scale to around 4 kW/m^2, assuming close-packed nanotubes. The ability to manufacture and assemble such nanotubes in practical quantities, if achieved, could be a game changer in the global power generation industry, said Dr Jerry Shan, who heads up the project, at a Rutgers graduate seminar staged this March.

Globally, there is the potential for more than 2.6 TW of power generating capacity – the equivalent of approximately 2,000 nuclear reactors – that could be generated at coastal estuaries from the mixing of fresh and salt water. 'Such a power density would be unprecedented for a renewable energy source, being three orders of magnitude better than the performance of prototype pressure-retarded-osmosis power plants,' Shan said.

Semih Cetindag, a PhD student in Dr Shan's Piscataway, New Jersey laboratory, reported at a December meeting of the USA Materials Research Society in Boston that the team has recently made a breakthrough by coating the BNNTs, which are not magnetic, with a coating of negatively-charged magnetic iron oxide particles. In that way the nanotubes, added to a polymer precursor spread and then into a 6.5 micrometre thick film, can be more easily aligned.

When the researchers applied a magnetic field, they found they could manoeuvre the tubes so that most aligned across the polymer film. They then applied ultraviolet light to cure the polymer, locking everything in place. Finally, the researchers used a plasma beam to etch away some of the material on the top and bottom surfaces of the membrane, ensuring the tubes were open to either side.

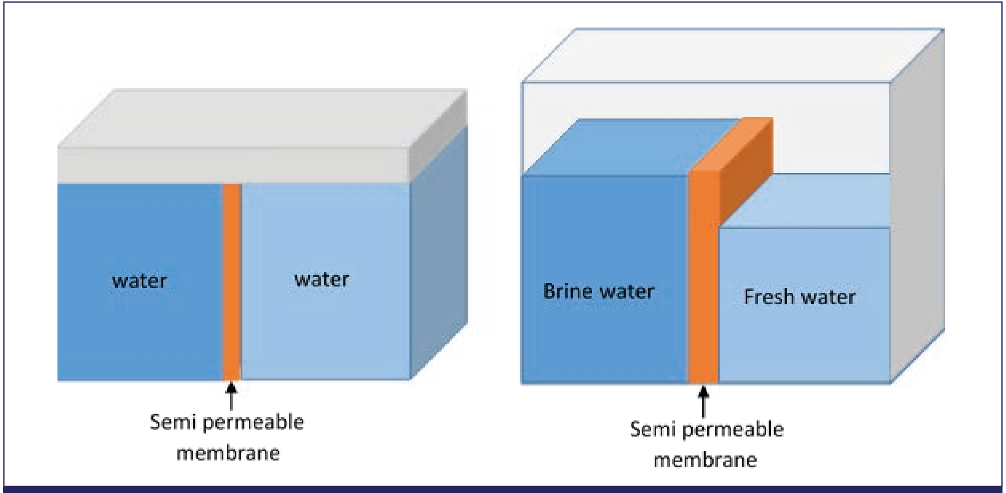
The final membrane contained some 10mn BNNTs per cubic centimetre, which is potentially a lot of holes in which to generate friction – and power. But the research is still dealing with problems – at present, after the plasma treatment, only 2% of the BNNTs were open on both sides of the membrane. 'We're not exploiting the full potential of the membranes,' Cetindag noted. 'Now, the researchers are trying to increase the number of open pores in their films – which could one day give a long-sought boost to advocates of blue energy.'

Pushing the boundaries

Elsewhere, researchers are also interested in the importance of light in accelerating and scaling up the process of osmotic power. This could theoretically be achieved using a system of mirrors and lenses directing light onto membranes at river estuaries, which can boost generating efficiency.

In a paper published last May, scientists from the Laboratory of Nanoscale Biology at the Ecole Polytechnique Fédérale de Lausanne, Switzerland, showed how shining a light on the process – via a membrane just three atoms thick – produced twice as much power as in the dark. The researchers used a low-intensity laser light to release embedded electrons and cause them to accumulate at the membrane's surface, which increased the surface charge of the material.

Another field of research is 'pressure retarded osmosis', which sees diluted, brackish water split into two flows: freshwater and brackish water. The brackish water is flowed through a turbine to generate power. In 2016, trials conducted by researchers from the University of Valladolid, Spain, at the mouth of the Magdalena River in Colombia, showed significant net



A simple graphical representation of osmosis *Source: Wikilakz*

power production .

The Copenhagen-based Climate Technology Centre & Network (CTCN) is interested in another membrane-based technology, known as reverse electrodialysis (RED), which uses an electrochemical reaction rather than osmotic pressure. The difference is that RED involves membranes that allow the salt ions – rather than the water molecules – to pass through.

Researchers at Wetsus, the European Centre of Excellence for Water Technology, at Leeuwarden in the Netherlands, are currently testing this technology. At REDstack – Wetsus' spin-off company – scientists have developed membranes that appear to 'breathe' by expanding and compressing like a pair of lungs as water ebbed and flowed. They found these could better harvest electricity, increasing net power production.

The device comprised a stacked series of membranes, half of which were permeable to sodium and half chloride, with seawater and freshwater flowing alternately between each pair of membranes. While most osmotic power has involved keeping membranes at a fixed distance by placing spacers between them, REDstack's 'breathing cell' concept did not fix them. Instead, researchers used pressure to control the intermembrane distance.

Jordi Moreno, of the University of Twente, who is involved in the research said: 'The breathing cell is a game changer. The movement of the membranes gives us the freedom to adapt the movement frequency, so it can harvest more energy at different flow regimes.'

One continuing challenge is the lifetime of membranes: CTCN says it must be extended to 10 years for commercial viability, compared to around two years at present. Another drawback is a dependency on clean water. Pollutants, plastic and algae get captured within a membrane's structure, reducing the flow through the membrane and causing reductions in power output.

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Demonstration potential

On the plus side, estuaries are not the only place where salt and freshwater meet and in 2019, the Danish company Nouryon conducted a demonstration project using salty discharge from a manufacturing plant in Mariagar, Denmark, to produce electricity. The project, which involved the Danish start-up company SaltPower, is based on the same osmotic principles, which it calls 'salinity gradient energy.'

In a separate project, SaltPower is investigating the production of electricity using hypersaline water from geothermal wells at Sønderborg, in southern Denmark. The process is mutually beneficial, says the company: by coupling salinity gradient energy with the heat generation in the geothermal process, the overall economic viability of geothermal plants can be increased.

SaltPower has directed its efforts towards hypersaline waters, said Henrik Tækker Madsen, the firm's Chief Technical Officer, because these contain more energy per cubic metre of water. 'The larger driving force would lower the amount of membranes required to build a system of a given size,' he said. 'We needed a widespread source of hypersaline water and we successfully identified several.' SaltPower has tested hypersaline water in a smaller 500 W pilot and more recently a 20 kW demonstrator. 'Based on these results, we are now looking to commercialise the technology,' Madsen told *Energy World*.

Despite its decision not to pursue blue energy, Hydro-Québec said it sees few environmental drawbacks in the technology. 'A number of steps could enhance the social acceptability of osmotic generating projects,' said Côté. 'Generating stations could be located at the mouth of a river where communities could already be found. This would eliminate or minimise the need to transmit electricity over significant distances.'

Professor René van Roij, Director of the Institute for Theoretical Physics, at Utrecht University, and colleagues have been exploring how the energy output from blue energy devices might be doubled if fresh water that is mixed with seawater is warmed (up to 50°C). Using fossil fuels to heat the water would contradict the environmental rationale behind blue energy, they stressed, instead, cooling water from power plants or data centres could be used.

The Institute's recent work has focused on the effects of the length of the channel (the thickness of the membrane), the diameter of the channel (the pore size of the membrane) and the influence of nearby channels on each other. 'The channel-channel interaction is of profound importance because the channels compete for ions at their inlet and reduce the ion concentration at the high-concentration sea-water side,' van Roij told *Energy World*.

Moreover, he and colleagues have found that channels 'compete to dump the ions at the outlet', which means ion concentration rises at the low-concentration river-water side and reduces efficiency. This, he warned, raised doubts about the theory that making the membrane as permeable as possible helps boost power output.

Given these unknowns, van Roij remains uncertain as to where blue energy will sit in the future renewable energy mix. 'I have changed my mind several times over the years, from excitement to disappointment and back and forth,' he admitted. 'But nanotechnology and nanoflows can definitely improve the traditional old-fashioned membranes.'

Madsen's outlook is somewhat sunnier: 'There's a big opportunity for osmotic power, it can run continuously 24/7 and provide baseload energy,' he said. 'The combined potential is sufficiently large to make the technology a third player in the clean energy market, with wind and solar.' ●