SCIENCE

New membranes could enhance efficiency of desalination process

PUB trials, if successful, will boost water and energy security as nation cuts reliance on fossil fuels

Cheryl Tan

National water agency PUB is trialling new technology aimed at making the energy-intensive desalination process more efficient.

Achieving this will help to boost Singapore's water and energy security, especially as the country moves to reduce its reliance on fossil fuels for energy.

Two new types of membranes will be tested at PUB's research and development (R&D) plant in Tuas to see if these are more durable, cost-efficient and energy-saving than the usual polymeric membranes used in the process to convert seawater to drinkable water, said PUB chief engineering and technology officer Pang Chee Meng.

The two types are ceramic membranes, and biomimetic membranes, which are made from material that mimics proteins found in nature.

Singapore, which lacks natural water resources, counts desalination as a way for it to safeguard its water security. Other strategies include importing water from Malaysia, collecting rainwater in reservoirs and treating used water.

But the desalination process is known to be energy-intensive, with traditional methods using about 3.5 kilowatt-hour (kWh) of electricity per cubic m of water. This is because high pressure is needed during the reverse osmosis process to push water through the polymeric membranes to filter out salts.

PUB aims to reduce the system-level energy consumption of desalination to less than 2kWh per cubic m of water.

Ceramic membranes, which are also being tested in other water treatment facilities here, are known to have longer lifespans, higher permeability and more robust chemical and physical properties.

Trials are also ongoing with Japanese water technology firm Meiden Singapore to determine the resilience of these ceramic membranes to various algal concentrations to ensure that they can withstand severe algae blooms, Dr Pang said.

Such blooms can occur in marine environments.

The company is currently constructing a 120 cubic m per day pilot at PUB's R&D facility in Tuas, which will be ready this month.

Biomimetic membranes, on the other hand, are thus named for the way they mimic natural biological systems, such as those found in mangroves.

Mangrove trees, which grow in seawater, have the unique ability to filter out high concentrations of salt from the water they take in.

They can also transport water from their roots up to the rest of the plant with minimal resistance.

Developing membranes that mimic these abilities can save a significant amount of energy because lower operation pressure would be required to operate the desalting process, said Dr Pang.

PUB is working with the Nanyang Environment and Water Research Institute (Newri) at Nanyang Technological University (NTU) to develop membranes enhanced with aquaporin proteins or synthetic biomolecules that help to improve their permeability.

Aquaporins are proteins found in living organisms that enhance the transfer of water through a cell membrane, while synthetic biomolecules are a new innovation that replicate the effect of these aquaporins – at a lower cost.

Professor Wang Rong, director of the Singapore Membrane Technology Centre at Newri, said these membranes are able to achieve at least 50 per cent enhancement in water permeability compared with commercial ones for seawater desalination.

A 10 cubic m per day pilot to scale up Newri's aquaporin-based biomimetic membranes is being constructed at the R&D facility in Tuas. It will be ready in September, and the pilot will last for six months.

Biomimetic membranes have also been used in the production of Newater – Singapore's brand of treated used water – and are being piloted at the Ulu Pandan Newater plant at a capacity of 14 cubic m per day.

Dr Pang told The Straits Times that a new desalination integrated validation plant will be located in Pasir Ris by next year. It will integrate, configure and optimise some of these technologies – including the ceramic and biomimetic membranes – to validate whether lower energy consumption and better performance can be achieved for desalination.

PUB had last October set itself a target of having emissions produced from water treatment processes in Singapore reach net zero by mid-century.

Other than doing research into new technologies, the agency is also moving to cut the carbon footprint of the water sector by increasing its use of renewable energy. For instance, the 60 megawatt-peak solar farm in Tengeh Reservoir will power all five of its water treatment plants that convert reservoir water into drinking water.

Dr Adil Dhalla, managing director of the Separation Technologies Applied Research and Translation Centre at NTU, said: "As Singapore moves towards including more renewable and clean sources of energy, any reduction in the use of fossil fuels would in turn make the water treatment process more sustainable.

"The other key goal is to improve the overall energy efficiency of the water treatment process. This of course includes more efficient membranes that work at lower pressure, but also, equally important, systems level process innovations in the overall desalination process, not just the filtration step."

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How desalination could be more energy-efficient

ABOUT DESALINATION

It is known to be an **energy-intensive process,** using about 3.5 kilowatt-hour of electricity per cubic metre (kWh/m^3) of water.

PUB is looking to reduce the energy consumption of desalination by **about 40 per cent** to less than 2kWh/m^3 to cut its carbon footprint. This involves using alternative membrane technologies and the following two are being tested:

Ceramic membranes which are more durable and resistant to algal blooms

Biomimetic membranes which mimic nature by using very low energy to transport water molecules efficiently while removing salts

DESALINATION PROCESS AT THE TUAS DESALINATION PLANT

1 **Intake**
Seawater is drawn into the plant through a huge underwater pipe.

2 **Screening**
Seawater undergoes a two-stage mechanical filtration process to remove coarse and fine particles.

3 **Dissolved air flotation**
Chemicals are added to mass impurities into bigger particles and fine air bubbles are pumped in to float these particles to the surface for easy removal as part of the clarification process.

4 **Ultrafiltration**
The seawater passes through ultrafiltration membranes to remove impurities, microorganisms and bacteria of smaller sizes.

5 **Reverse osmosis**
Comprises two processes: Sea water reverse osmosis (SWRO) and brackish water reverse osmosis (BWRO)
The seawater is pumped at high pressure through these semi-permeable membranes to separate dissolved solids. Only water molecules can pass through the membranes at this stage.

6 **Post-treatment**
The water is disinfected, re-mineralised and made potable by adding chemicals such as chlorine and fluoride.

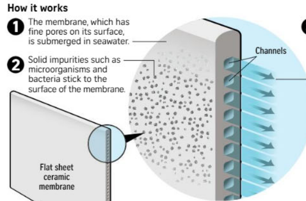
NEW METHODS AND HOW THEY WORK

Flat sheet ceramic membranes

These could potentially replace both stages of the treatment process.

How it works

1. The membrane, which has fine pores on its surface, is submerged in seawater.
2. Solid impurities such as microorganisms and bacteria stick to the surface of the membrane.
3. Filtered, clean water is then gathered via channels and transported out of the membrane.



Advantages

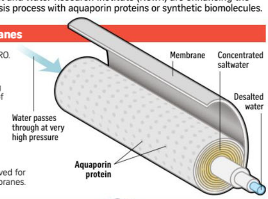
Compared with polymeric membranes that are currently in use, these ceramic membranes
- Have longer lifespans
- Have higher permeability
- Are more tolerant towards fouling, which is the accumulation of unwanted material on solid surfaces, and algal bloom situations

About 0.3kWh/m^3 is saved by using these membranes, equivalent to about **60 per cent of energy** savings for both stages.

Researchers at Nanyang Environment and Water Research Institute (Newri) are enhancing the membranes used in the reverse osmosis process with aquaporin proteins or synthetic biomolecules.

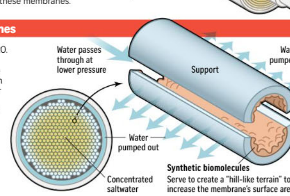
Flat sheet biomimetic membranes

- These membranes will be used for SWRO.
- Membranes are coated with a layer containing aquaporin molecules.
- Aquaporins are proteins found in living organisms which enhance the transfer of water through the cell membrane.
- They reduce the resistance for water transport and allow for higher water permeability, and can save around **10 per cent of energy** in pumping water.
- About 0.3kWh/m^3 of energy can be saved for the desalting process using these membranes.

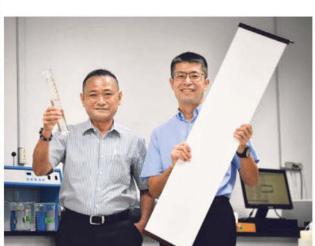


Hollow fibre membranes

- These will be used for BWRO.
- They are fitted with biomolecules which increase the membrane's contact with water molecules, allowing for higher water permeability.
- About 0.2kWh/m^3 is saved by using these membranes, equivalent to about **40 per cent of energy** needed for pumping.



Sources: PUB, NEWRI, MEIDEN PHOTO: ISTOCKPHOTO STRAITS TIMES GRAPHICS



Above: Meiden's Dr Hiroshi Noguchi (left) and Dr Terutake Niwa, seen here with a ceramic membrane. Trials are ongoing with the Japanese water technology firm to determine the resilience of such ceramic membranes to various algal concentrations to ensure that they can withstand severe algal blooms.

Right: Dr Lai Gwo Sung (left), a research fellow at Newri, and Professor Wang Rong, director of the Singapore Membrane Technology Centre at Newri, with sheets of biomimetic membrane. These membranes are named for the way they mimic natural biological systems, such as those found in mangroves.
ST PHOTOS: CHONG JUN LIANG, ALPHONSUS CHERN

IMPROVING ENERGY EFFICIENCY

As Singapore moves towards including more renewable and clean sources of energy, any reduction in the use of fossil fuels would in turn make the water treatment process more sustainable. The other key goal is to improve the overall energy efficiency of the water treatment process.

DR ADIL DHALLA, managing director of the Separation Technologies Applied Research and Translation Centre at Nanyang Technological University.