Filtration+Separation (UK)
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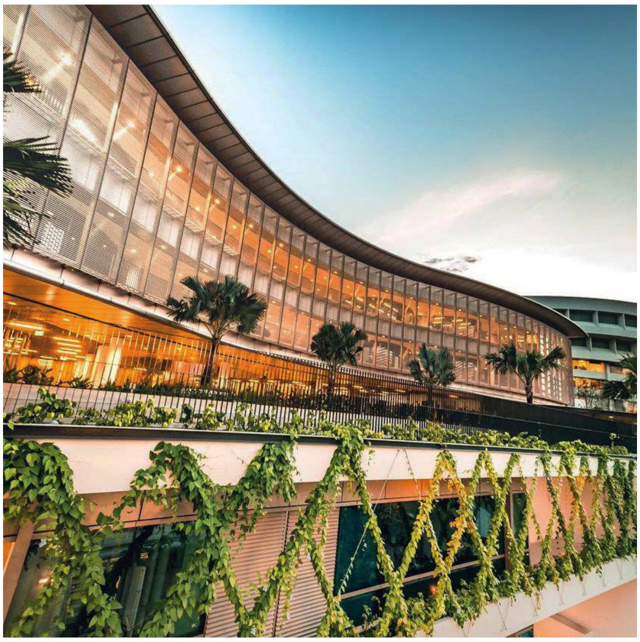
Advancing water treatment for a sustainable future

In a new series on universities, we put a spotlight on Nanyang Technological University, Singapore (NTU Singapore), a research-intensive public university and home to the Nanyang Environment & Water Research Institute (NEWRI).

Water is essential for all living things, from the tiniest microorganisms to the tallest trees. The United Nations estimates that the average person in the United States uses 590 litres of water a day for activities such as bathing and drinking. But in Mali, due to factors like access to clean water and lifestyle, water use stands at 11 litres a day.

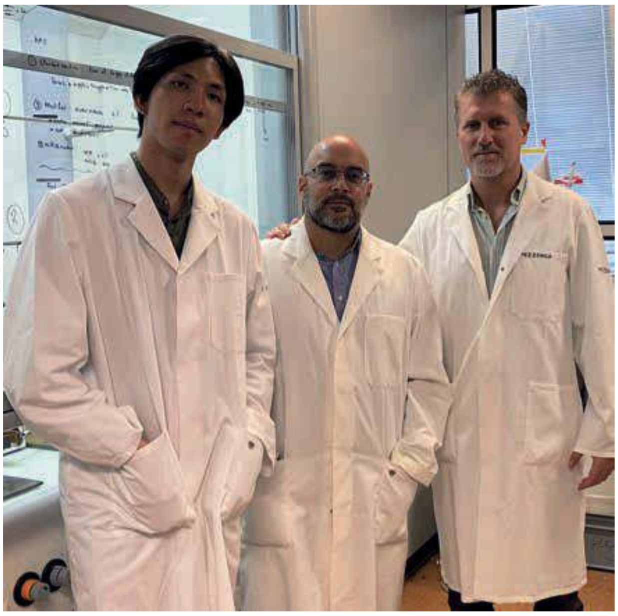
Given its importance in sustaining life, the United Nations has made the availability and sustainable management of water and sanitation for all one of its Sustainable Development Goals. Yet for billions of people around the world, especially those in developing regions, the lack of access to clean water for drinking, hygiene and sanitation is a pressing issue. In densely populated countries with limited land to collect and store rainwater, ensuring a sustainable supply of water is an important priority. Climate change and pollution are also making the supply of clean water more difficult.

To address the water challenges faced by communities and countries around the world, researchers from Nanyang Technological University, Singapore (NTU Singapore) are developing innovations to purify water, as well as to treat wastewater effectively.



One of NTU Singapore's learning hubs known as The Arc. (Image: NTU Singapore)

HEAVY METAL FILTER



The scientists who developed the heavy metal filter made from plant waste. (From left) PhD student Soon Wei Long; Prof Ali Miserez; and NTU Visiting Professor Raffaele Mezzenga. (Image: NTU Singapore)

The contamination of water by heavy metals is a serious environmental and public health concern. As a result of mining and industrial activities, water sources such as rivers and groundwater are increasingly susceptible to such pollution. Using plant waste from the production of peanut and sunflower oils, scientists from NTU Singapore and ETH Zurich, Switzerland (ETHZ) have created a low-cost way to filter out toxic heavy metals from water, so that it meets international drinking water standards.

The research is led by Prof Ali Miserez of NTU's School of Materials Science & Engineering and the School of Biological Sciences and NTU Visiting Professor Raffaele Mezzenga from ETHZ's Department of Health Science and Technology. The team first extracted proteins from oilseed meals, protein-rich by-products left over from the production of vegetable oils and turned them into nano-sized amyloid fibrils, which are rope-like structures made of tightly-wound proteins.

The scientists then made a hybrid membrane from these fibrils and activated carbon – a commonly-used filtration material. Acting like a molecular sponge, the amyloid fibrils trap heavy metal ions in the water as they pass through the membrane, in a process called adsorption.

According to lead researcher Soon Wei Long, a PhD student from NTU's School of Materials Science & Engineering, this is the first time that amyloid fibrils from peanut and sunflower proteins have been used to purify water.

The researchers found that the membrane removed up to 99.89% of heavy metals. Among the three metals tested, the filter was most effective at removing lead and platinum, followed by chromium.

The researchers estimate that 16 kg of sunflower seed protein would be needed to filter an Olympic-sized swimming pool of water contaminated with 400 parts per billion (ppb) of lead.

"Unlike conventional filtration methods, our protein-based membranes are created through a green and sustainable process, and require little to no power to run, making them viable for use throughout the world and especially in less developed countries," says Prof Miserez.

The scientists are currently exploring the commercial applications of their membrane with BluAct, a Europe-based water filtration spinoff company of ETH Zurich and pilot tests on the filter are underway in Peru, Sri Lanka and India, which commonly face heavy metal contamination in their drinking water supply.

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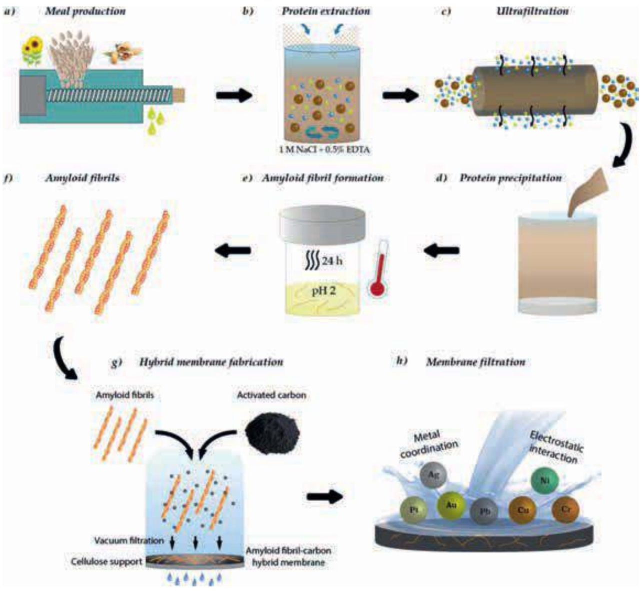
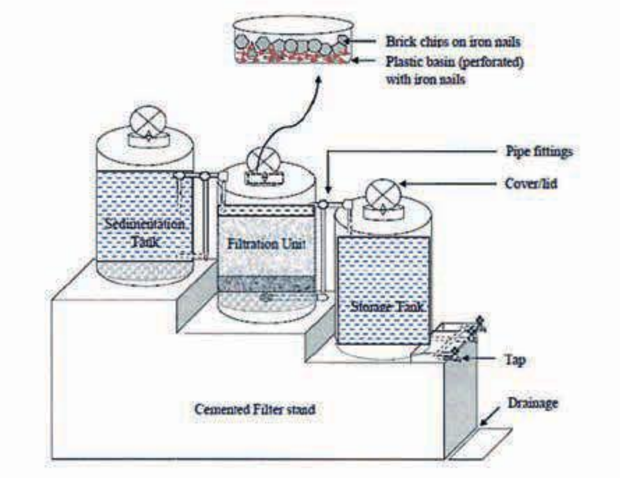


The process of converting plant waste from the production of peanut and sunflower oils to a membrane that can remove heavy metals from water. (Image: NTU Singapore)

REMOVING ARSENIC



The biosand filter system comprising three tanks. (Image: NTU Singapore)

Researchers from NTU Singapore and Nepal have constructed a bio-sand filter system that removes toxic arsenic found in groundwater to deliver safe drinking water for children and their communities in Nepal. The project is supported by the Lien Environmental Fellowship (LEF), a non-profit programme that empowers academics and researchers from selected South and Southeast Asian countries to tackle water and sanitation challenges in their home countries.

Located in the Newalparasi district, a region in Nepal with elevated levels of arsenic in its groundwater, the clean water facility comprises three 1,000-litre tanks arranged in a descending order. The sedimentation tank is placed on the highest stand. Here, particles suspended in water are allowed to settle out. Next, the water is transferred to the middle tank, where it is filtered using a combination of iron nails, brick chips and sand. Arsenic in the water is attracted to the iron in the nails and removed from the water. The clean water is then stored in the third and lowest tank, which users can easily access through taps.

The simple design of the system makes it more sustainable to maintain in the long term without the need for specialised technical support, according to Prof Shane Snyder, executive director of NTU's Nanyang Environment and Water Research Institute (NEWRI). NEWRI provided the engineering and technical expertise for the water facility construction through its philanthropic arm NEWRI Community Development (NEWRIComm).

The facility is expected to benefit more than 600 students and staff of the Shree Janta Secondary School in the district.

DESALINATION MEMBRANES

NTU Prof Wang Rong, the director of the Singapore Membrane Technology Centre at NEWRI (left), and the centre's research fellow Dr Lai Gwo Sung with a roll of an aquaporin-based membrane and the machine that makes the membrane. (Image: NTU Singapore)

In land-scarce countries like Singapore, getting enough clean and drinkable water can be a challenge because there is insufficient space to build reservoirs to collect and store it.

By removing salt from seawater, desalination is an important tool to meet the growing demand for drinkable water. It involves a process called reverse osmosis in which high pressure is used to force seawater through partially permeable membranes, to separate the water molecules from contaminants like salt.

However, this process requires a lot of energy, which is generated through the burning of fossil fuels. To improve the energy efficiency of desalination, NTU Singapore's NEWRI is working with Singapore's national water agency PUB to test new membranes that reduce the energy used during desalination. Prof Wang Rong, the director of the Singapore Membrane Technology Centre at NEWRI who is leading the research, says: "Compared with commercial membranes for desalination, these new membranes are 40–50% more permeable to water, so they need less energy for removing the salt to get the same amount of pure drinking water. Using less energy helps reduce carbon emissions, which is important with mounting concerns over climate change."

One of the membranes developed by Prof Wang and her team is embedded with water-channel proteins called aquaporins. These proteins, which enable water to be transported rapidly into plant and animal cells, significantly improve the membrane's permeability to water. Another membrane they developed uses biomolecules that can also improve its water permeability.

As water molecules can pass through these membranes more easily, the energy required to pump water through the membranes during desalination is 10% less than that for conventional desalination membranes.

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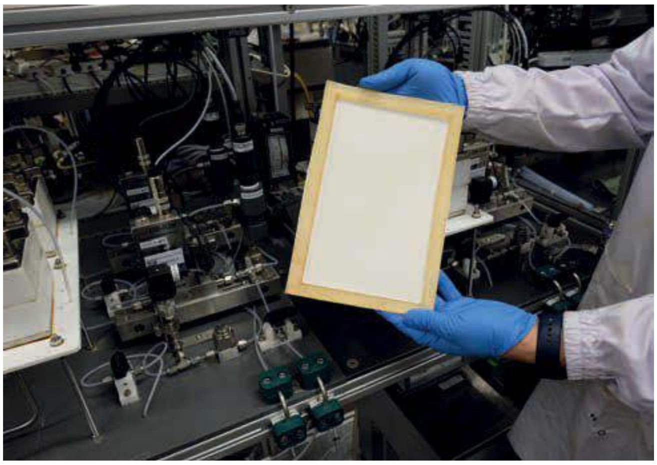
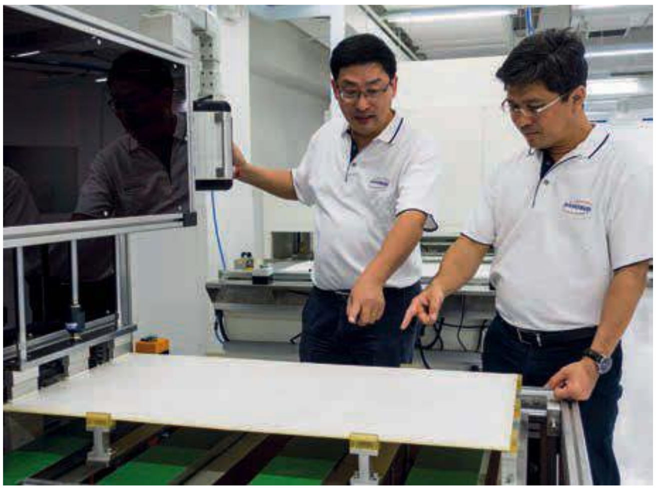


The aquaporin-based membrane and the equipment used to test its performance. (Image: NTU Singapore)

3D-PRINTED MEMBRANES



NTU Singapore Assoc Prof Darren Sun (left) and Nanosun co-founder Wong Ann Chai. (Image: NTU Singapore)

With rising industrialisation and urbanisation, there is a growing need to treat the wastewater that results and minimise the pollution it causes before it is discharged.

NTU Singapore's Assoc Prof Darren Sun, who is from the university's School of Civil and Environmental Engineering, has developed a membrane that can filter wastewater more quickly than existing membranes.

The technology has been commercialised by NTU Singapore spinoff Nanosun, which seeks to develop and deploy membrane solutions to solve wastewater pollution challenges.

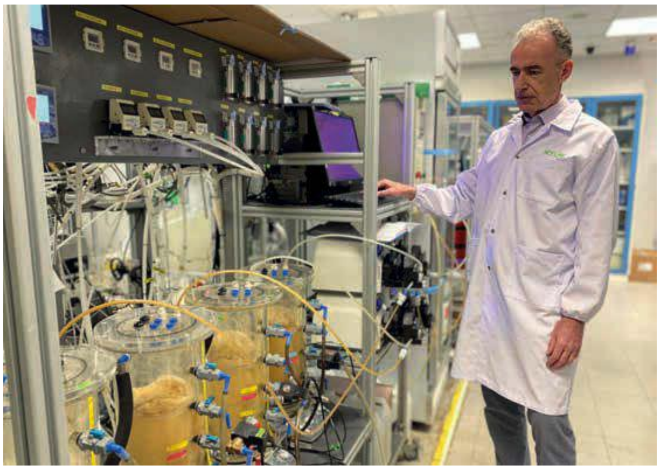
In contrast to conventional membranes that are manufactured using traditional techniques to make polymers porous so that they can act as filters, Nanosun's membranes are made by 3D printing millions of polymer nanofibres. These fibres, each five times thinner than a strand of hair, are layered over one another and fused into a thin sheet to form the membranes.

The structure of the membrane increases its surface area for trapping or repelling contaminants, while allowing water molecules to pass through five times faster than traditional polymer membranes.

The manufacturing process is also less labour intensive than that for traditional membranes as it is fully automated and needs 30 times less manpower. It also requires 10 times less space, according to Prof Sun, who is also Nanosun's co-founder.

Nanosun has tendered and won projects deployed in China, Indonesia, the Philippines, Singapore, and Thailand, for treating industrial and municipal wastewater. To date, the company estimates it has treated over 18 million tons of water cumulatively since the deployment of its solutions.

USING BACTERIA TO REMOVE PHOSPHORUS IN WASTEWATER



Prof Stefan Wuertz, SCELSE's deputy centre director, with the bioreactors in which the experiments with bacteria and wastewater were conducted. (Image: SCELSE)

Rising temperatures, a result of global warming, are expected to hamper processes that remove phosphorus from wastewater, but NTU researchers have found a workaround using bacteria.

High levels of phosphorus in the environment from sources such as untreated wastewater may encourage the rapid growth of algae. Such algal blooms are dangerous – they lead to oxygen depletion in the water when dead cells decompose and may release high levels of toxins, both of which can kill aquatic life like fish.

However, current biological methods to remove phosphorus in wastewater before it is discharged may not be effective at temperatures above 25°C.

Using the Candidatus Accumulibacter bacteria, Singapore Centre for Environmental Life Sciences Engineering (SCELSE) scientists at NTU Singapore and the National University of Singapore developed a method to remove phosphorus from wastewater that works at temperatures above 25°C.

The bacteria, which are found in wastewater treatment plants, can take up phosphorus from wastewater beyond what is needed for growth and store it as polyphosphate granules in their cells.

In experiments, the researchers – led by NTU Prof Stefan Wuertz, who is SCELSE's deputy centre director – grew the bacteria in reactors kept at a neutral pH and at temperatures of 30–35°C. After six hours, the bacteria removed most of the phosphorus from the wastewater, and this continued to be observed over 300 days.

"Our solution could not only help future-proof biological phosphorus removal, but also store the element and then re-introduce it into agricultural systems," says Prof Wuertz, who is also from NTU Singapore's School of Civil and Environmental Engineering.

Singapore's national water agency PUB, which was also involved in the research, will consider the study's results in the design of future water reclamation plants.

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