DHI CASE STORY

IMPROVED WATER DESALINATION WITH AQUAPORIN

Optimising membrane performance production with Computational Fluid Dynamics

Aquaporins are proteins found in living cells, which facilitate highly efficient water transport in and out of the cells. Synthetic aquaporin films can also be formed to potentially improve water desalination at reduced operational costs and low energy consumption. The Environment and Water Industry (EWI), Programme Office of Singapore funded a research project to develop such a product and ultimately make it available for commercial use in Singapore. As part of a collaborative effort between us, Nanyang Technological University (NTU) and Aquaporin A/S, we brought our expertise in Computational Fluid Dynamics (CFD) to the table. In so doing, we contributed to an increased understanding of the water flow through the polymer membrane. The results will be used to optimise the experimental procedures in aquaporin polymer membrane production.

PROVIDING CLEAN WATER BY DESALINATION

Clean water is becoming a precious resource worldwide. As such, cheaper methods of clean water provision are fast becoming the need of the hour. Singapore, being highly dependent on Malaysia for clean water, wishes to become more independent and is therefore pushing for ways and means to provide clean water efficiently and sustainably. This has given rise to the emphasis on desalination and re-using wastewater to compensate for the country's own lack of this precious resource.

Desalination is the process of removing salt and other minerals from saline water. Large scale desalination processes are usually very energy-intensive. They are also often cost-inefficient, on account of the expensive infrastructure.

This is where the aquaporin biomimetic membrane (a membrane that attempts to mimic or emulate a real biological cell) comes in.

AQUAPORIN: A MIRACLE PROTEIN

Aquaporins are special proteins found in the cells of all organisms. These integral membrane pore proteins facilitate rapid, highly selective water transport through water-impermeable lipid membranes of living cells. In fact, aquaporins (also commonly known as 'water channels') selectively conduct water molecules in and out of the cell, while preventing the passage of ions and other solutes. This allows the cell to regulate its volume and internal osmotic pressure according to hydrostatic and/or osmotic pressure differences across the cell membrane.

The understanding of aquaporins and their role in life has opened the possibility of using aquaporins in an industrial context. By mimicking living cell membranes

SUMMARY

CLIENT

Environment & Water Industry (EWI), Programme Office

CHALLENGE

- Increasing need for provision of clean water worldwide
- High energy consumption and operating cost of contemporary desalination methods
- Need to properly understand water flow through synthetic aquaporin membranes, which can provide alternative cost-effective water desalination

SOLUTION

Computational Fluid Dynamics (CFD) modelling for improved understanding of water flow through aquaporin membranes

VALUE

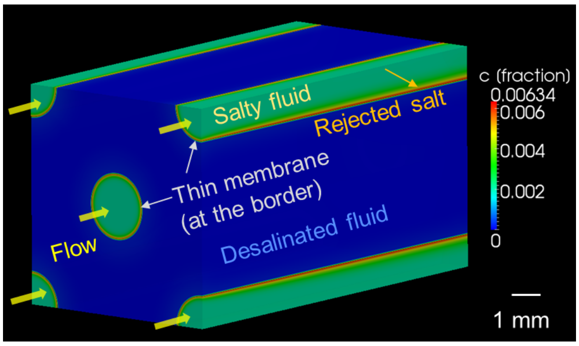
- Understanding and optimisation of experimental aquaporin membrane production procedures
- Increased possibility of clean water production through desalination at lower energy consumption and operating cost

LOCATION / COUNTRY

Singapore, Denmark

containing aquaporin, similar synthetic membranes can be formed. The aquaporin channels are first incorporated into cell -like spherical shells (vesicles), which are then altogether embedded into a thin polymer film. Such an aquaporin-rich active layer may have the ideal transport properties for water reuse and desalination application – high water permeability coupled with high salt rejection. Compared to mainstream water reuse and desalination methods (such as reverse osmosis), aquaporin biomimetic membranes can potentially produce better quality water at lower energy consumption and operating costs. This is on account of its remarkable selectivity and high water permeability.

The goal of our partner – Aquaporin A/S – is to use aquaporin in such polymer biomimetic membranes as cornerstones in water filtering devices, for use in industrial and household water filtration and purification.



Reverse osmosis with incorporated aquaporin membrane

CONTRIBUTING TO THE AQUAPORIN MEMBRANE DEVELOPMENT WITH CFD

With a sponsorship of USD 3 million, EWI financed a cutting edge research project known as 'Aquaporin Based Biomimetic Membranes for Water Reuse and Desalination'. It aims at developing aquaporin biomimetic membranes with sufficient stability for cost-effective water reuse and desalination. The R&D work focused on making biomimetic membranes and improving their stability through:

- aquaporin production
- support structure permeation and optimisation
- aquaporin-polymer film formation and anchorage onto support
- performance evaluation
- simulation and modelling
- scaling up

The goal of the entire project was to commercialise the results of the research.

We linked NTU with Aquaporin A/S and participated as a part of the consortium in the R&D project.

The production of aquaporin biomimetic membrane prototypes was a complex, multi-stage procedure. It required the concentration of protein within vesicles or concentration of vesicles within the active layer to be optimised within strict experimental protocols. Furthermore, experimental tests of water permeability and salt rejection were done on overall, composite membranes (no measurements on isolated vesicles were available). In order to suggest improved designs or investigate theoretical limits of performance, we resorted to modelling. This, on the other hand, required individual parameters including those of the aquaporin vesicles. We therefore had to combine several disciplines – molecular structure, thermodynamics and fluid dynamics – to arrive at the correct multi-scale parameterisation of the biomimetic system. We then developed a detailed CFD model with the said parameters. This helped us to understand the flow of water through idealised biomimetic membranes. The model was in excellent agreement with experiments and quantified the amount by which the current design be enhanced.

A STEP TOWARDS COMMERCIAL PRODUCTION

By conducting these modelling studies and analyses, we directly contributed to the process of improving aquaporin membranes. When these findings are successfully applied to commercial production, water reclamation by these state-of-the-art water purifying membranes could potentially be brought to every household worldwide.

There were also certain unexpected benefits from our studies. We learned the formalism behind ordinary reverse osmosis and then modified it to make it applicable to biomimetic-based reverse osmosis. We now also understand how to model and parameterise each scale and link them together – from protein size channels (nanometre size) to macroscopic membrane sheets (metre size).

In 2013, Aquaporin Asia – the joint venture between Aquaporin A/S, DHI Singapore and NTU - will commence membrane development activities in Singapore.

ENVIRONMENTAL & WATER INDUSTRY (EWI) - FUNDING

Aquaporin Asia is a spin off from the EWI-funded project 'Aquaporin Based Biomimetic Membranes for Water Reuse and Desalination'. This is the project in which the 1st generation Aquaporin Inside™ Membrane was developed in collaboration between the Singapore Membrane Technology Centre (SMTC) - under the NEWRI Insitute of Nanyang Technological University (NTU) - DHI Singapore, and Aquaporin A/S.

CLIENT TESTIMONIAL

> *DHI's CFD work has given us a better understanding of our membranes. This may very well result in significant improvements of the Aquaporin Inside™ technology."*
> *Mark Perry—COO—Aquaporin A/S*

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