12.2.2 Aquaporins

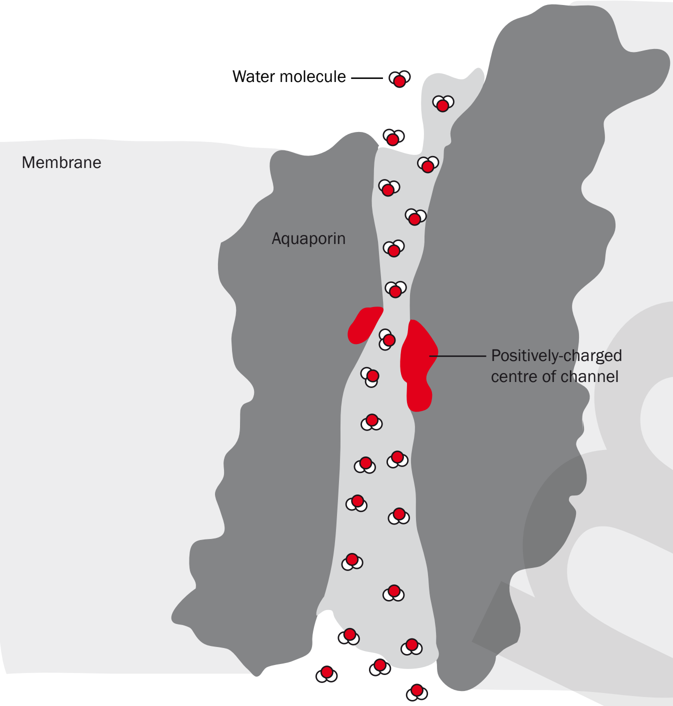
Concept

Biomimetic membranes are designed to mimic the highly–selective transport of water or solutes across cell membranes. One promising biomimetic membrane technology employs natural proteins known as **aquaporins** to regulate the flow of water, providing increased permeability and near–perfect solute rejection. Two aquaporins, AQP1 and AQP2, exist in the human kidney to facilitate and regulate water transport through the cell wall; there are many other aquaporins with similar structures.

How aquaporins work

Aquaporins act as water channels which **selectively allow water molecules to pass through** in single file while the transport of ions, protons and hydroxyl ions is abrogated by an electrostatic tuning mechanism of the channel interior. Smaller molecules are also restricted passage because their electrochemical properties do not 'fit'. The result is that only water molecules, but nothing else, can pass through aquaporin water pores. Aquaporin membranes are said to be 100 times more permeable than commercial RO membranes.

Figure 12.x: Passage of water molecules through aquaporin



Source: Figure based on Protein Databank structure of AQP1
PDB ID: 1J4N, Sui et al, Structural basis of water-specific transport through the AQP1 water channel, Nature 2001 Dec 20-27;414(6866):872-8.

As figure 12.x shows, positively charged ions are deflected because of the positive charge at the centre of the channel. This mechanism prevents proton leakage through the channel. These membranes seem to offer **significant potential for water treatment and desalination technologies**.

Disadvantages

One difficulty in commercialising biomimetic membrane is to make them as stable and strong as polymeric membranes so they are able to withstand the operating pressures and repeated fouling and cleaning events expected to be encountered in most full–scale applications.

Development

Johns Hopkins University's Peter Agre won a Nobel Prize for the discovery of the aquaporin water channel in 2003. Research on aquaporin membranes and their use for desalination applications is currently being undertaken by several groups.

Groups / Companies offering this technology

Aquaporin A/S: This Danish company's primary strategy is to develop an aquaporin membrane capable of separating and purifying water for ultrapure water applications. The secondary application is to develop a membrane for seawater desalination and pressure retarded (forward) osmosis applications. The company is developing a 2-dimensional biomimetic membrane with embedded aquaporins able to support pressures to 10 bar with a water flux in excess of 100 l/m3/h. Therefore the development of the technology is closely linked to the simultaneous development of suitable porous support materials.

Danfoss AquaZ: This Danish company is focused on developing membranes that can be gravity–driven to increase water throughput 5 – 10 times over conventional membranes. The key is likely to be the use of an appropriately matched aquaporin. Different aquaporins have varying functionalities in different environments. Matching the aquaporin with the membrane material could produce an effective nanomembrane that is scalable and can be produced in industrial processes.

According to Jørgen Steen-Pedersen, CEO of Danfoss AquaZ, the use of polymer (artificial) membranes supports a 3-dimensional membrane structure, up to 100 nm in thickness, which can contain a higher population of aquaporins in comparison to traditional 2-dimensional membranes. This higher redundancy of aquaporins leads to superior selectivity in water purification, compared to traditional 2-dimensional living membranes (5 – 6 nm in thickness).

University of Illinois: While assembling a protein–polymer membrane, an aquaporin found in E-coli bacteria is added to make a pore in the membrane through which only water can pass. By varying the amount of this aquaporin, the membrane's permeability can be increased to 10 times that of conventional salt–rejecting polymeric membranes which do not contain aquaporins.

Currently, these experimental protein-polymer membranes exist only as small vesicles. The next step is to scale up the technology, producing larger, more practical membranes optimised for maximum permeability.

Mantemagno et al., Patent (2007): In this patent, biological membrane proteins are incorporated into a co-polymer matrix to produce membranes with a wide variety of functionalities. In one form of the invention, a composite membrane incorporates two different proteins, which cooperate to produce electricity from light. In another form, water transport proteins are embedded in a membrane to enable water purification.

Potential / Verdict

These membranes seem to offer significant potential for water treatment and desalination technologies. They could represent a step–change in membrane performance by significantly reducing the net driving pressure required to desalinate water while greatly improving product water quality. Due to its higher energy efficiency, aquaporin technology is estimated to reduce desalination energy costs by 70 – 80% when compared to traditional reverse osmosis desalination techniques.

Commercialisation seems to be several years away and may be most appropriate for applications that operate at lower pressures (e.g. forward osmosis) or require very high purity water (e.g. pharmaceutical or industrial process applications).

Potential market value

The global market for the use of aquaporin in water purification is estimated in the region of US$[redacted] per year. The market to some extent overlaps with the reverse osmosis and nano filters markets, which are estimated to be in the region of US$[redacted] and US$ [redacted] per year, respectively. Furthermore, the market for products used to produce ultra pure water for other applications is estimated to be worth more than US$[redacted] per year globally.

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