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Aquaporin-Based Membranes in Forward Osmosis: Removal of Trace Organic Contaminants and Water Recovery from Urine

Introduction:

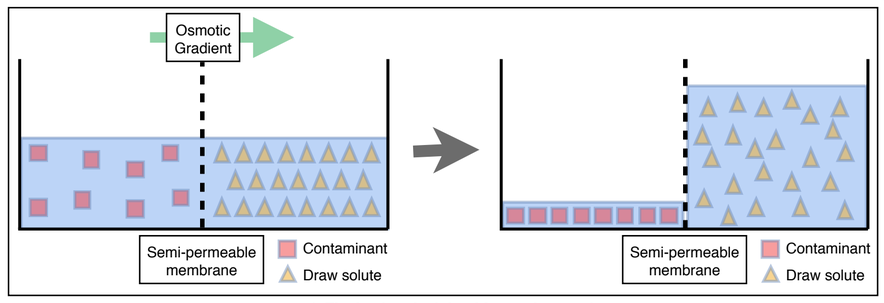
- Trace organic contaminants are becoming an increasing concern for the preservation of clean water sources [1-4]
- Conventional water purification strategies such as reverse osmosis (RO) have several disadvantages (e.g. membrane fouling, high costs etc.) [5,6]
- Forward osmosis (FO) is a promising key strategy for energy efficient water purification

Forward osmosis:

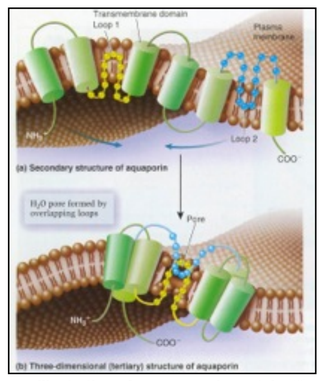
- A draw solution, that creates an osmotic gradient, can be engineered to be recovered in a secondary step (e.g. ammonium bicarbonate) [6-8]
- Main challenges for FO membranes: high trace organic rejection and sufficient water permeability [6]
- Novel aquaporin-based membranes are promising candidates to be used in FO

Aquaporin-based membranes (ABMs):

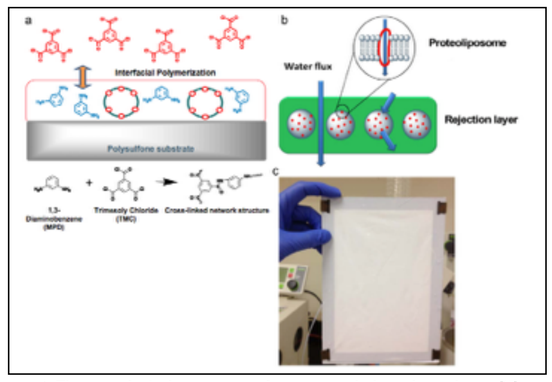
- Aquaporins are trans-membrane proteins that can be found in all domains of life [9]
- Some aquaporins are exclusively permeable to water [10-12]
- Ions are rejected from permeating through the aquaporin by an electrostatic barrier and a narrow constriction (2.8 Å) inside the channel's pore [10,13,14]
- 3×10^9 water molecules per second can permeate through a single aquaporin subunit [14,15]
- Aquaporin-Z from *E.coli* has successfully been embedded into artificial membranes [16,17]



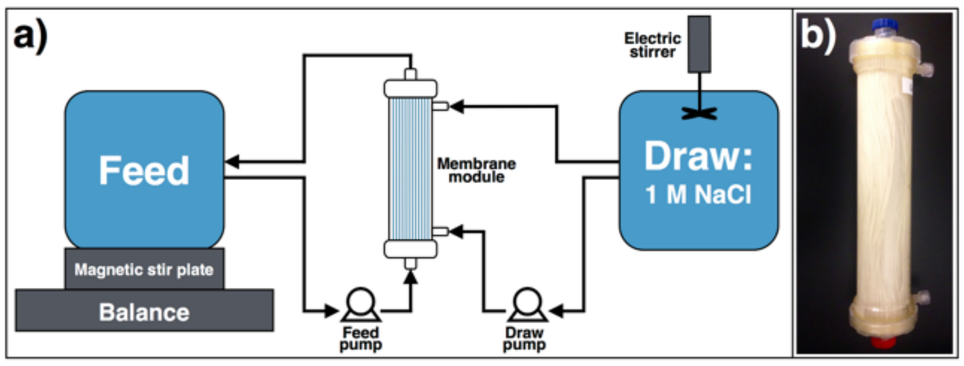
▲ The basic principle of forward osmosis



▲ Illustration of an aquaporin protein [18]



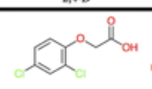
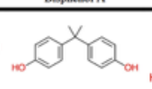
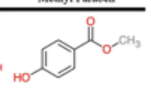
▲ The manufacturing process of an aquaporin-based membrane [17]



▲ (a) Schematic overview of the FO setup and (b) an image of the membrane module used in this study

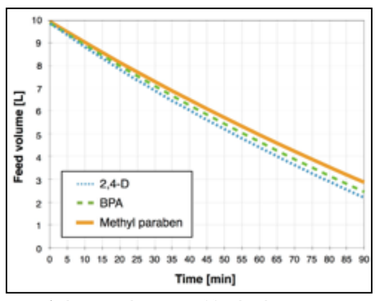
Experimental:

- A 0.6 m^2 hollow fibre ABM module (Aquaporin Inside™ membrane) was tested for its rejection of three common trace organic contaminants: 2,4-D, BPA & methyl paraben
- Feed solution concentrations of 1 mg/L and 10 mg/L were tested
- A 1 molar NaCl draw solution was used in all experiments
- The initial volume of feed and draw solution was 10 L in each experiment
- High Pressure Liquid Chromatography (HPLC) with a detection limit of 0.01 mg/L was used as the analytical method to quantify the amount of contaminant in the feed and draw streams

Compound	2,4-D	Bisphenol A	Methyl Paraben
Molecular structure			
Formula	$C_8H_6Cl_2O_3$	$C_{15}H_{16}O_2$	$C_8H_8O_3$
Molecular weight (g/mol)	221.04	228.29	152.15
Length (nm)	0.852[a]	1.068[b]	1.002[a]
Width (nm)	0.545[a]	0.587[b]	0.412[a]
Heigth (nm)	0.306[a]	0.383[b]	0.151[a]
Volume (nm^3)	0.142	0.240	0.062

[a] Molecular dimension were estimated by 3D molecular modelling using the Cambridge structural database available at https://www.ccdc.cam.ac.uk/structures
[b] Molecular dimension data were obtained from [Xie et al., 2012]

▲ Structural chemical properties of the three compounds tested



▲ Average decrease of feed volume over time for the three contaminants tested

Results:

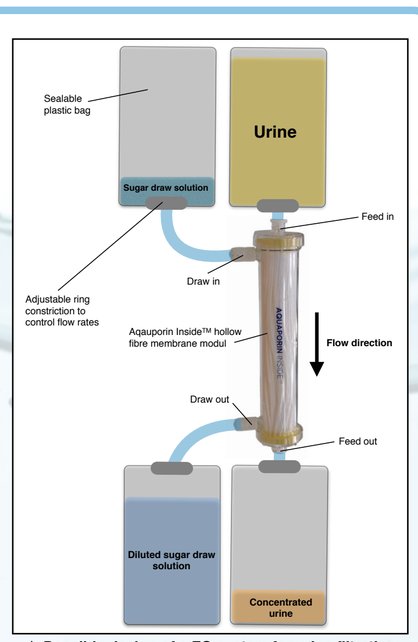
- High rejection rates could be achieved in all experiments
- Methyl paraben was the only contaminant that could be measured in the final draw solution
- BPA and methyl paraben adsorbed on the membrane during the experiment and were flushed out in subsequent experiments

Initial feed concentration	2,4-D	BPA	Methyl paraben
1 mg/L	> 99.4 %	> 99.0 %	> 95.6 %
10 mg/L	> 99.8 %	> 99.9 %	> 96.2 %

▲ Average membrane rejection rates for 2,4-D, BPA and methyl paraben

Outlook:

- Since the results described above show that relatively small molecules could be rejected, it is likely that a variety of waste streams can be processed by FO using ABMs
- ABMs may be suitable to be used for urine filtration due to their high water permeability and solute rejection characteristics
- Light-weight and portable FO-systems with ABMs are conceivable to be used to recover water from urine into a drinkable sugar draw solution to reduce the urine's weight and volume
- Possible application fields: Space stations and space travel, long-term explorations of remote locations with limited access to drinking water etc.
- Current focus of study: Development of a light-weight forward osmosis system that can be used during long-term cave exploration where waste products such as urine have to be dealt with
- Challenges to be addressed: Identify optimum volume to concentration ratio of the draw solution to achieve the highest possible volume reduction of the urine stream while limiting the amount of draw solute that has to be brought into the cave; Maximize the membrane's rejection capabilities of the urine's solutes such as urea; Develop an energy efficient or energy neutral pumping mechanism of the final system



▲ Possible design of a FO system for urine filtration

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Background image taken from: http://az616578.vo.msecnd.net/files/2017/02/25/636236375094082231210822182 1_eau.jpg

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