ElectroOsmoDialysis

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ELECTRO-OSMO-DIALYSIS

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Outline

- Electrodialysis (ED)
- Electroosmosis (EO)
- Concentration polarization (CP) and limiting current in ED
- Convection as an effective tool for reducing CP in ED
- How to arrange for a “through” convection across ion-exchange membranes (IEXMs): micro-perforation of IEXMs and their “conjugation” with nanoporous membranes.
- Numerical simulation of Electro-Osmo-Dialysis
- Important differences from ED: no limiting current, noticeable volume transfer (potentially, better recovery), asymmetry (possibility of using capacitive electrodes without stream commutation)
- Examples of preparation of micro-perforated IEXMs
- Conclusions and Outlook

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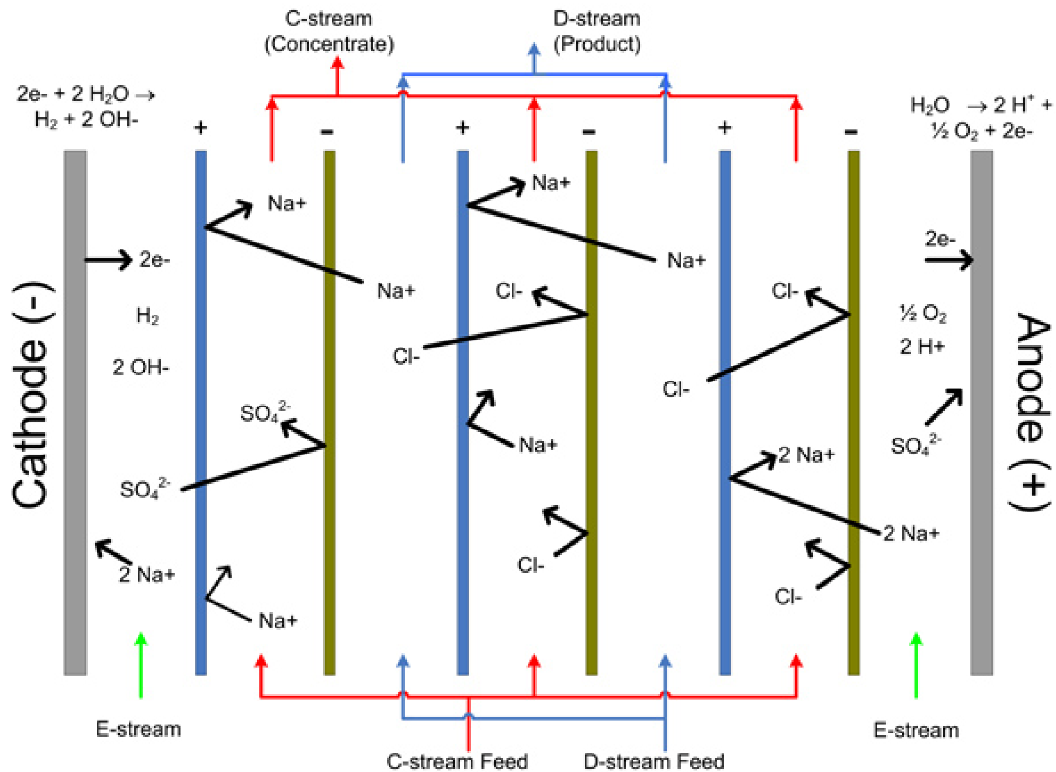
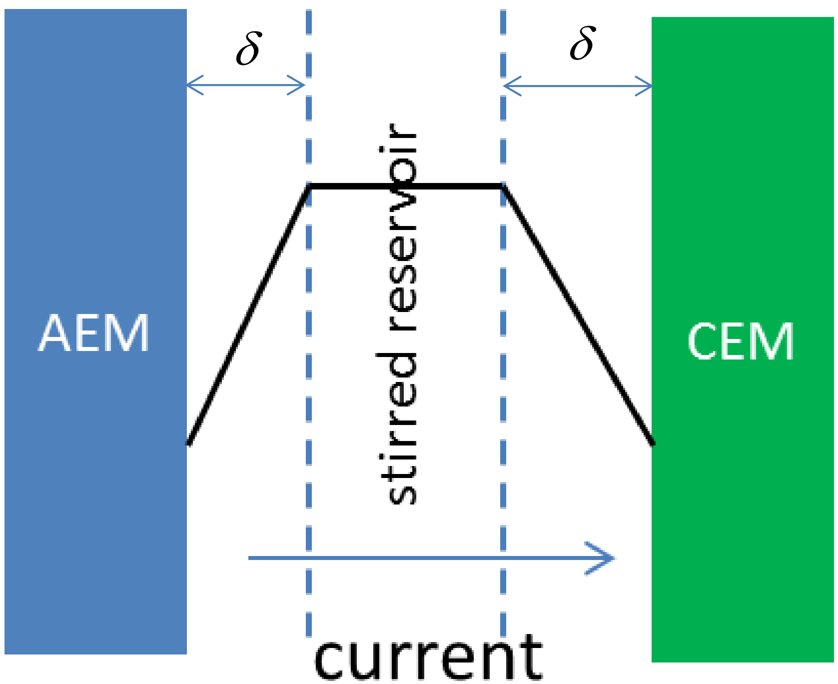
Electrodialysis



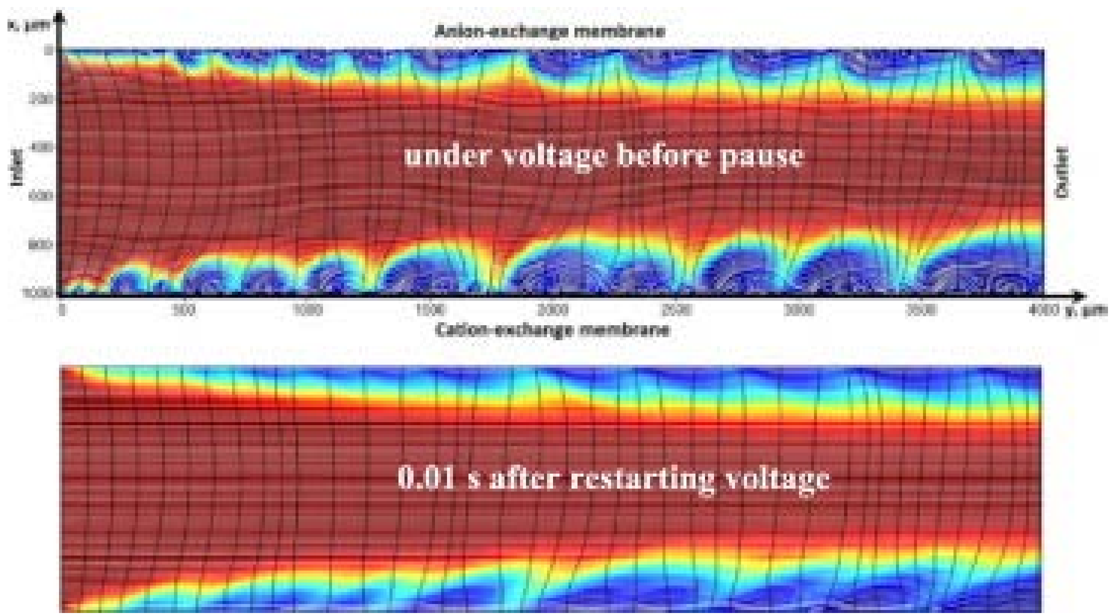
Courtesy EET Corporation
www.eetcorp.com

Electrodialysis: limiting current



$$I_{\lim} \approx \frac{F D_s c_0}{\delta \cdot (t_{+m} - t_{+s})}$$

Electro-convection as a mechanism of over-limiting currents



A.M. Uzdenova, A.V. Kovalenko, M.K. Urtenov, V.V. Nikonenko, Effect of electroconvection during pulsed electric field electrodialysis. Numerical experiments, Electrochem.Comm., 51 (2015) 1-5

Convection is a very effective salt-transport process yet tangential convection is often inefficient due to the no-slip condition at solid surfaces.

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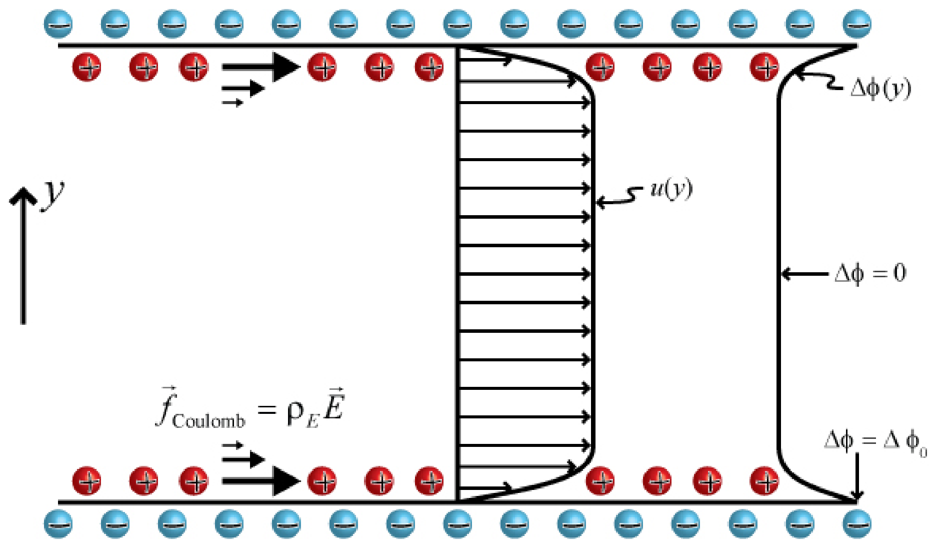
Electroosmosis



Electroosmosis is a preferred liquid-delivery tool in microfluidics because it is much more efficient at micro-scale than pressure-driven flows.

$$J_v = \frac{\varepsilon \varepsilon_0 \zeta}{\eta} \cdot E$$

electric field

Smoluchowski formula; rate of EO is independent of the pore size (if the pores are not too small).

In very small (sub-nanometer) pores (ion-exchange membranes) EO is very weak.

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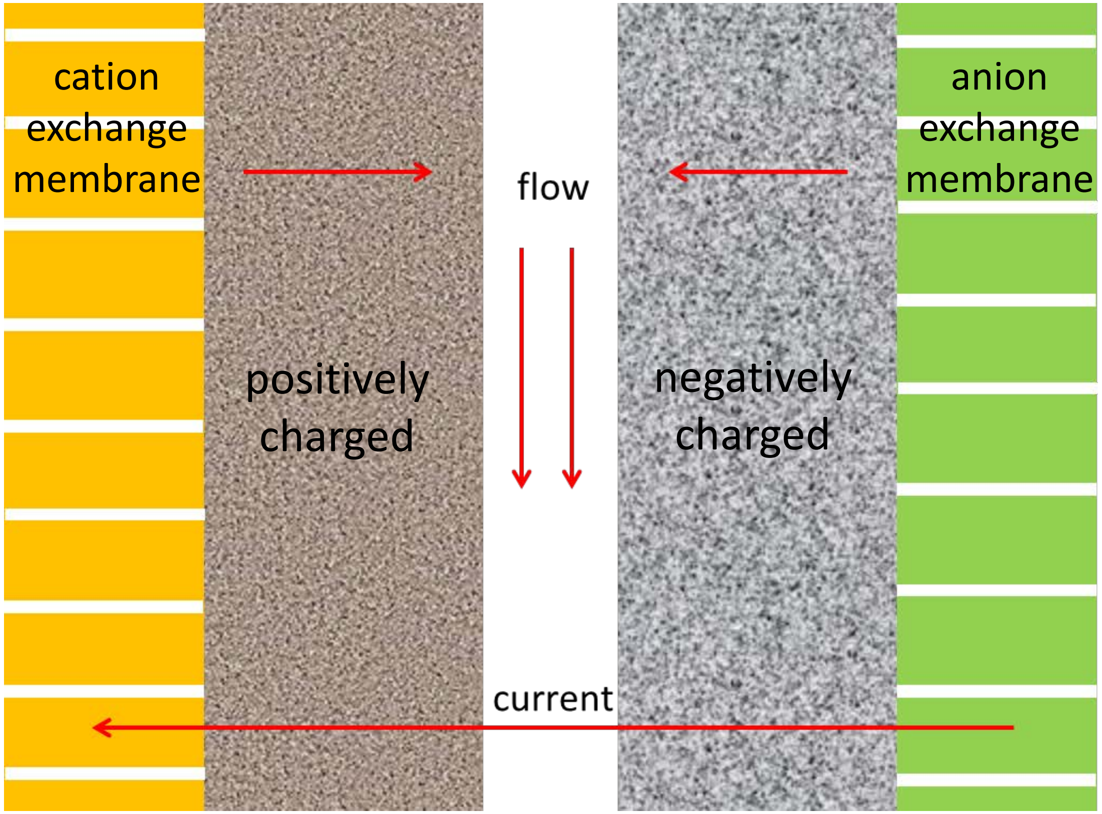
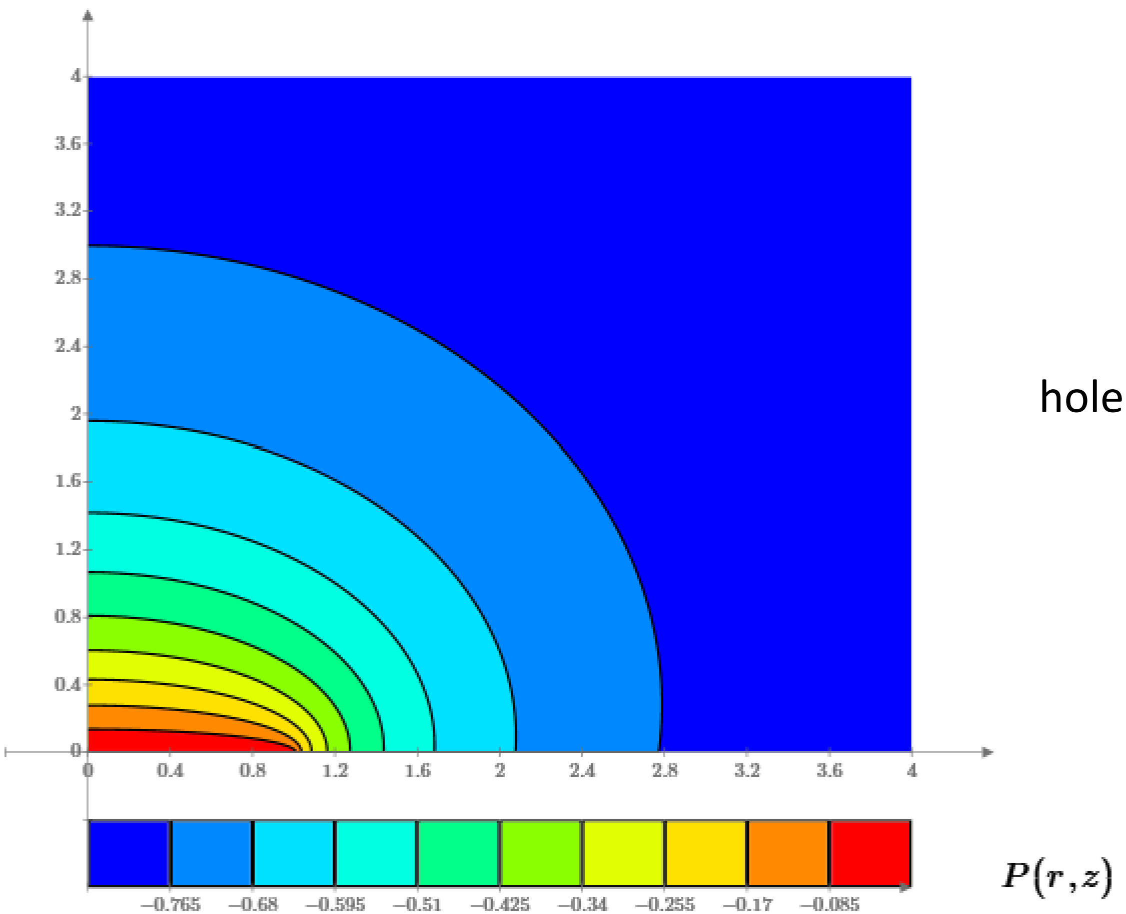
Schematics of Electro-Osmo-Dialysis



Distribution of effective pressure within nanoporous medium



hole radius 1 µm

flow rate is proportional to the gradient of effective pressure

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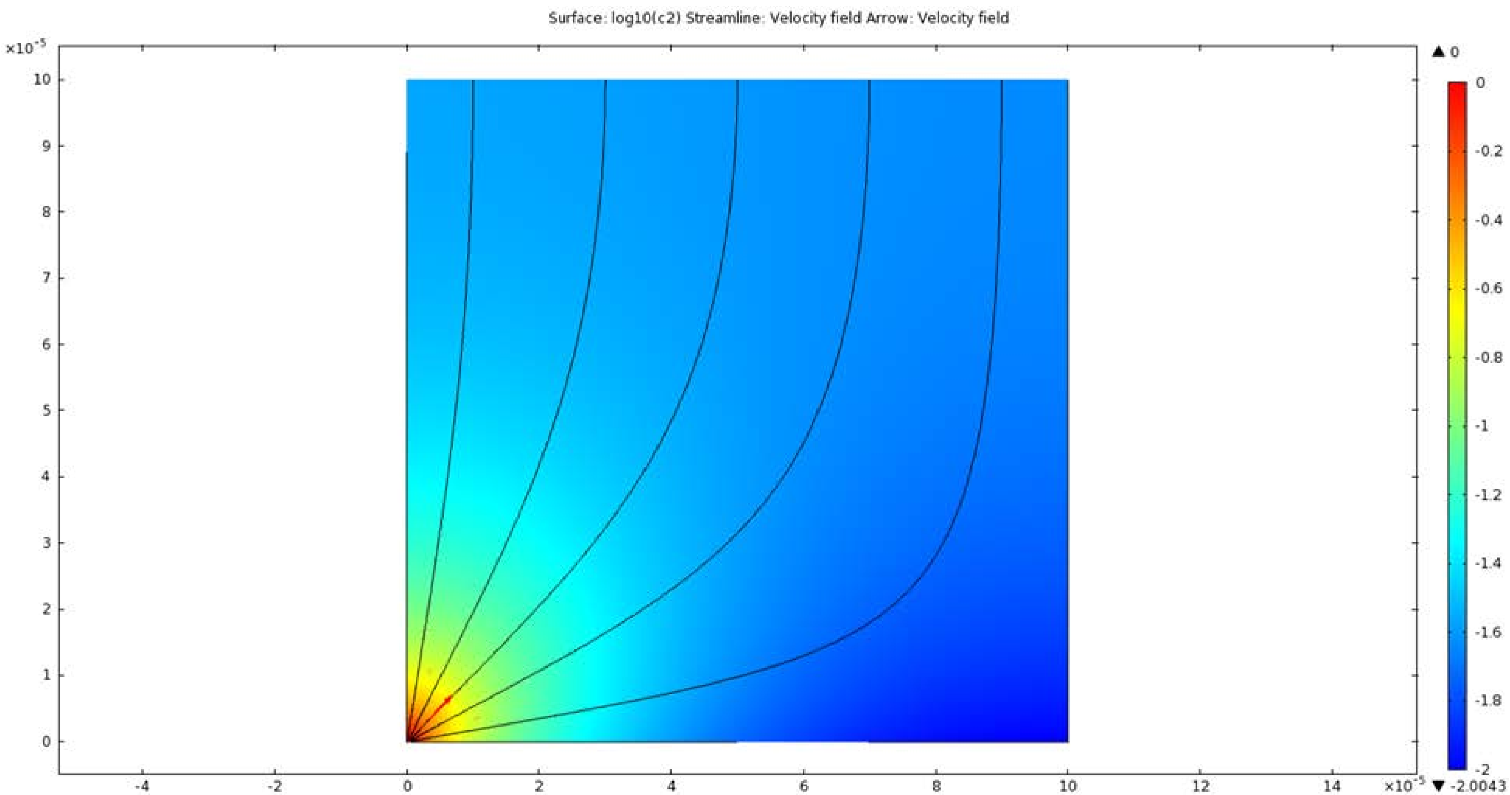
Distribution of concentration and flow streamlines within nano-porous layer



$\zeta = 50\ mV$

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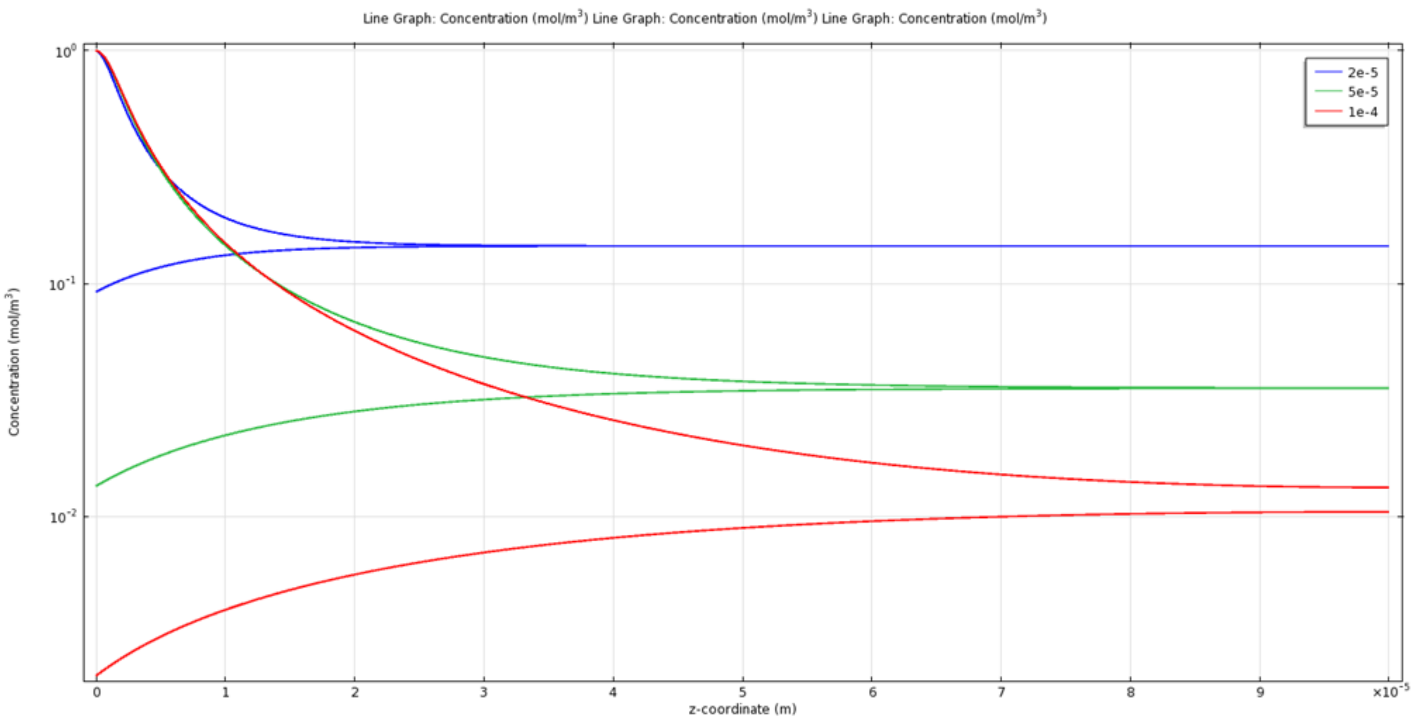
Establishment of 1D distributions across nanoporous layer



$\frac{interhole\ distance}{layer\ thickness}$

0.4

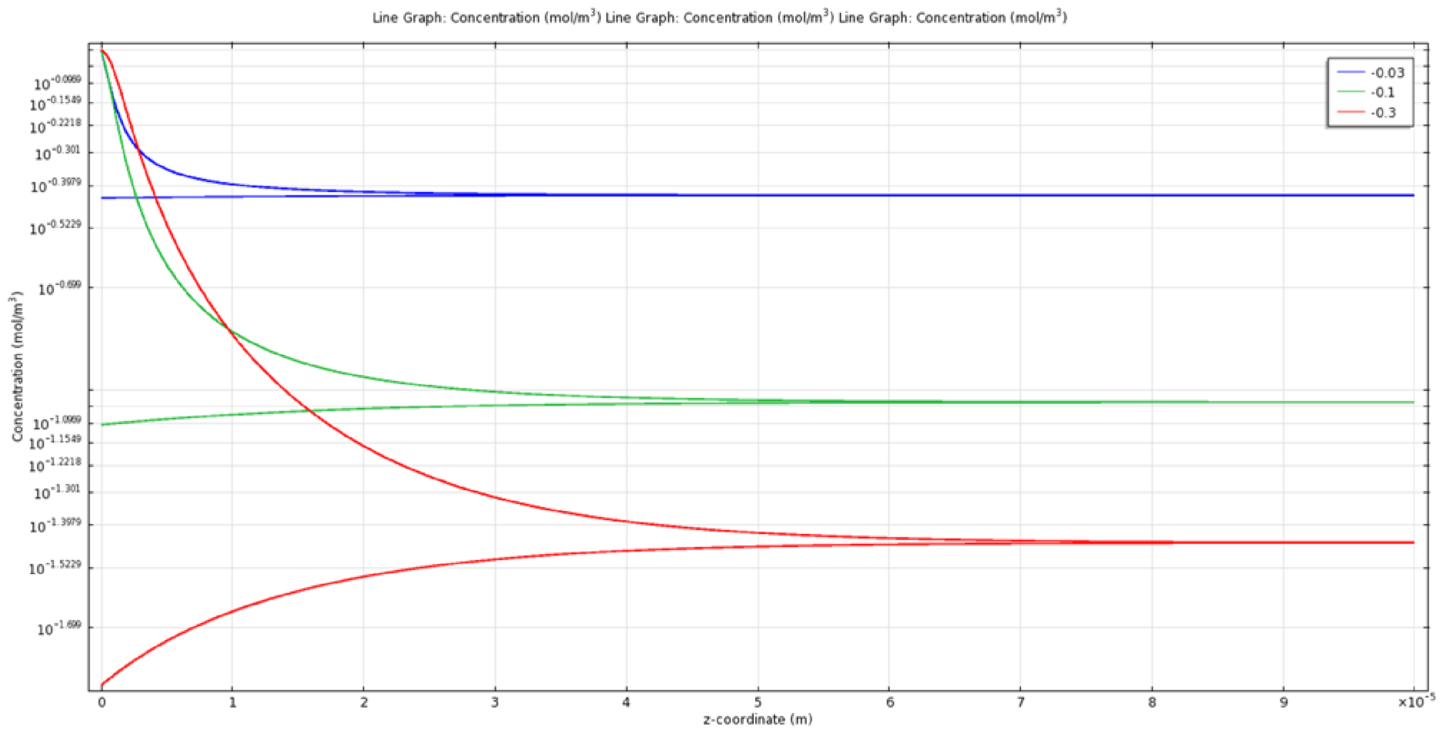
1

2

$\Delta\varphi = 300\ mV$

Establishment of 1D distributions across nanoporous layer

voltage



30 mV

100 mV

300 mV

$$\frac{interhole\ distance}{layer\ thickness} = 1$$

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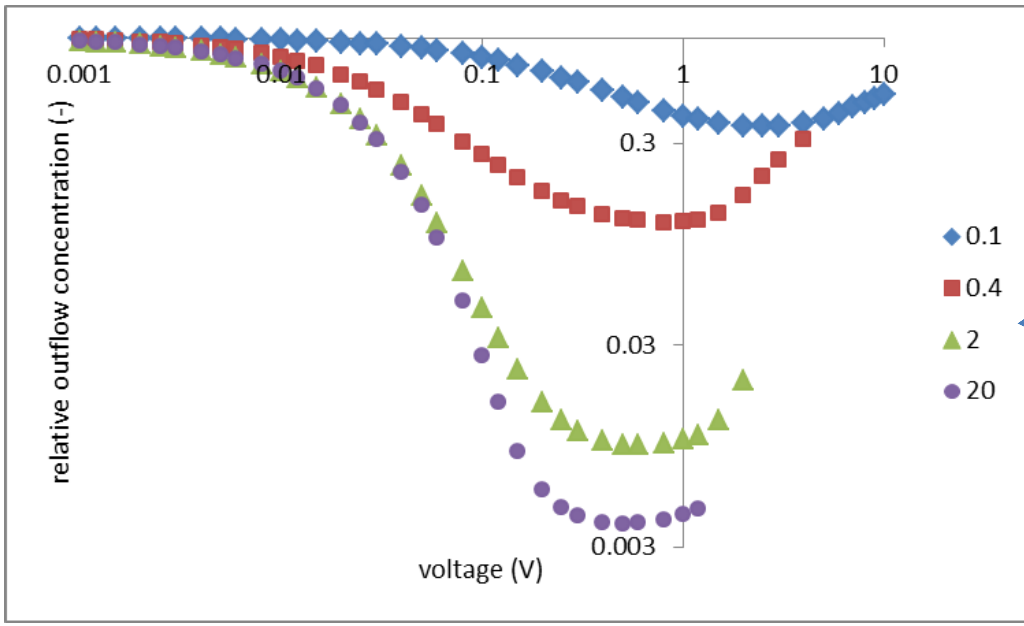
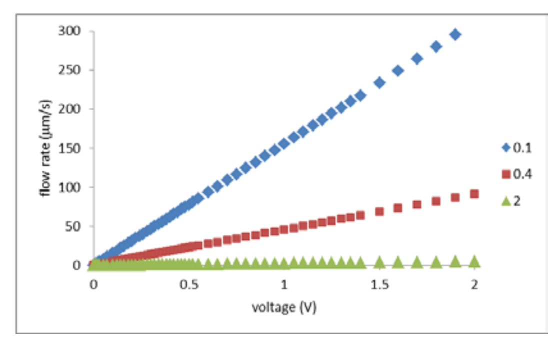
Desalting vs applied voltage

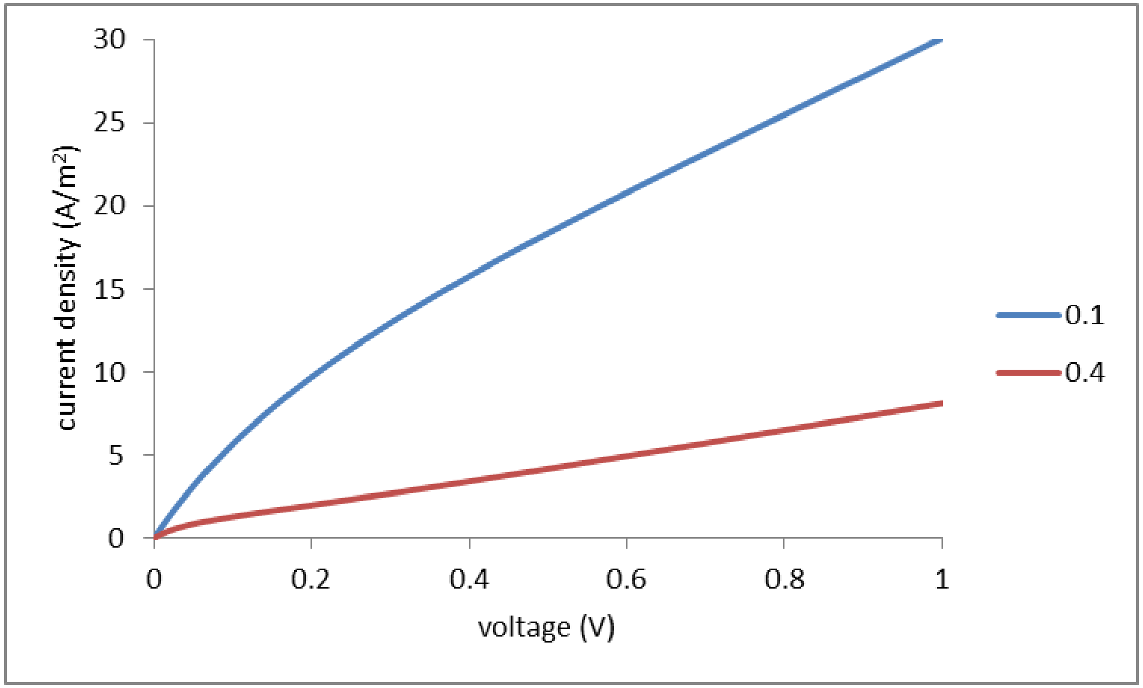


$$\frac{interhole\ distance}{medium\ thickness}$$

$$\zeta = 25\ mV$$

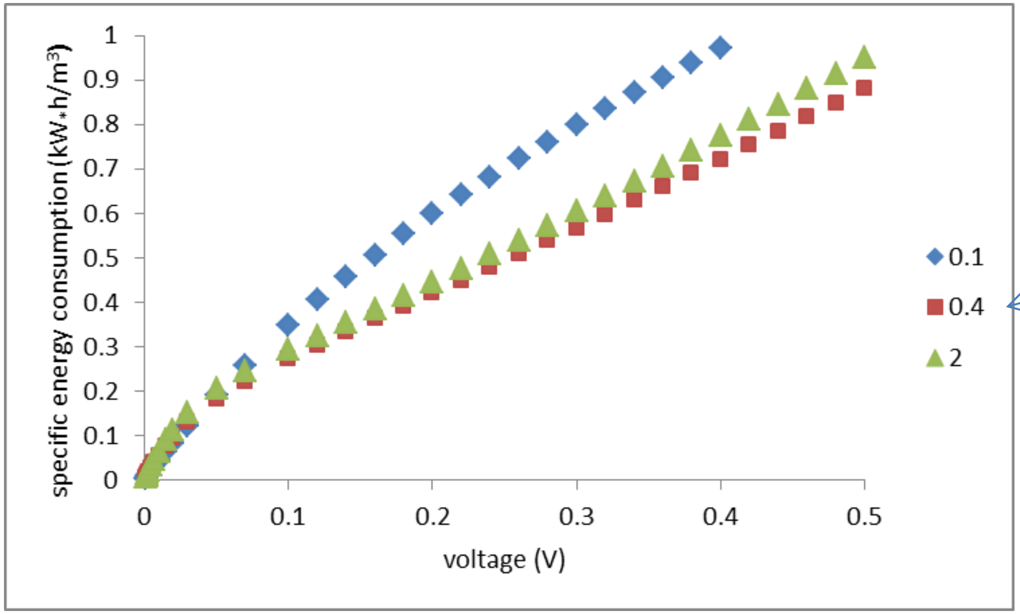


Current-voltage characteristics



$c_0 = 1\ mM$

Specific energy consumption in desalination of brackish water



$$\frac{interhole\ distance}{layer\ thickness}$$

2000 ppm NaCl

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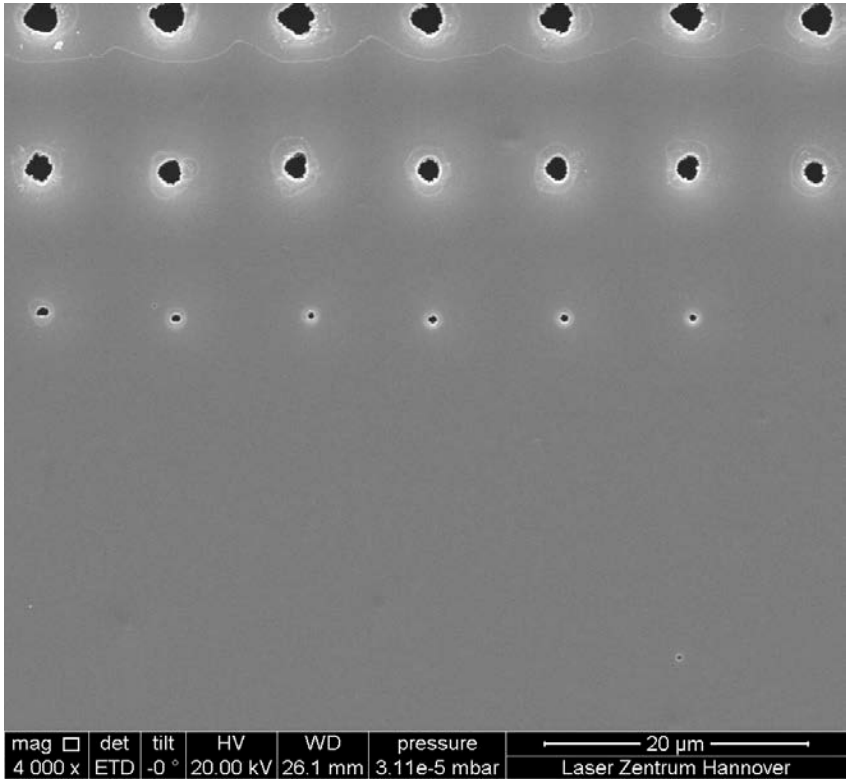
Perforation scenarios: laser drilling



Laser Zentrum Hannover

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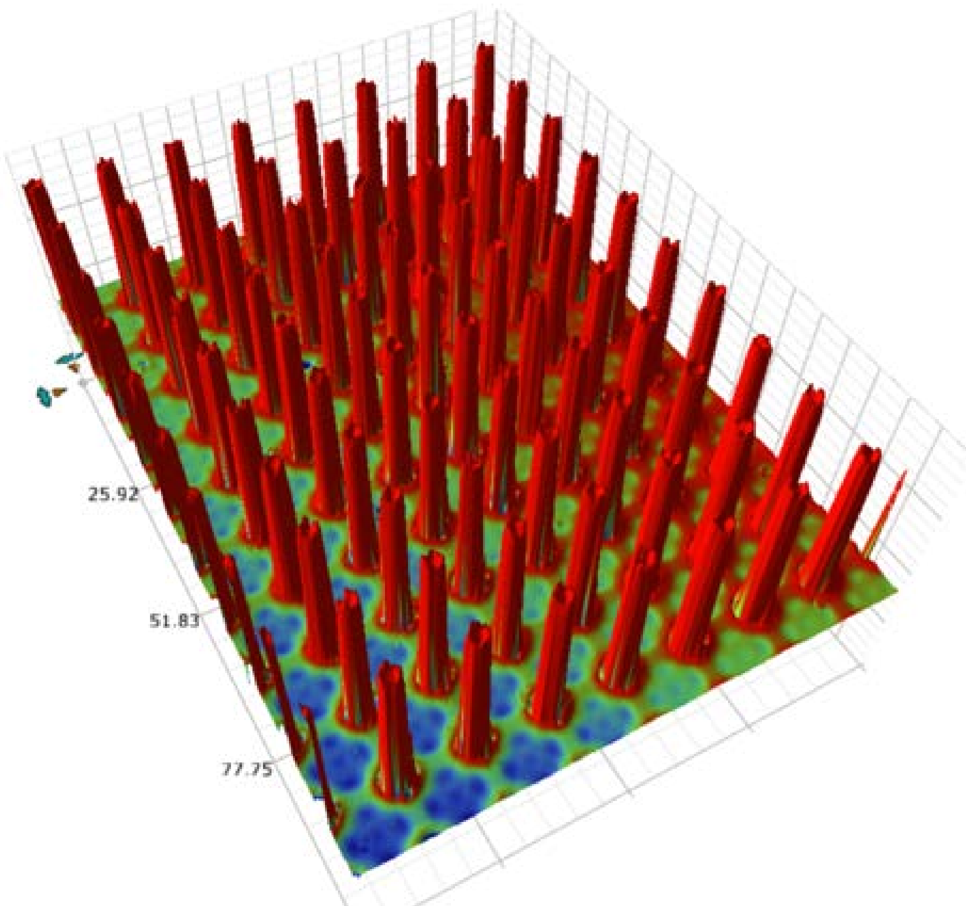
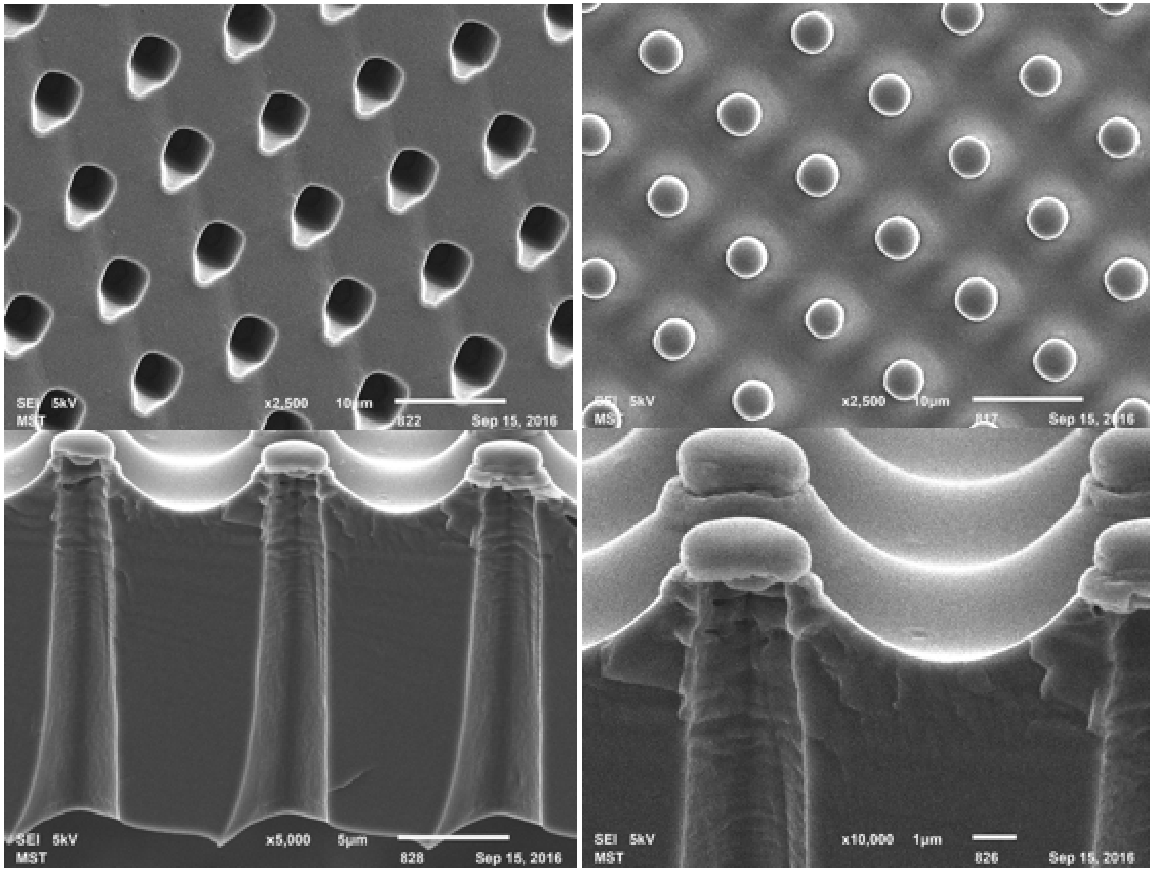
Perforation scenarios: template molding



3D image of the silicon mold

European Membrane Institute Twente

Perforation scenarios: template molding



Conclusions and Outlook

- Numerical analysis shows that the processes of Electrodialysis and Electroosmosis can be beneficially combined via conjugation of ion-exchange and nanoporous membranes.
- To allow for volume flow across dense ion-exchange membranes, they should have scarce microscopic openings (holes, perforations).
- Despite such extreme inhomogeneity the flow and concentration fields become 1D at short distance from the interface between the perforated IEXM and nanoporous layer.
- Due to some convective passage of salt through the openings there is no limiting current; nonetheless, the outflow concentration can be considerably reduced (desalination effect).
- In contrast to the conventional electrodialysis, in EOD the salt transfer is accompanied by the volume transfer in the opposite (beneficial) direction; therefore, one can increase the use of pre-treated water (better product recovery).
- The process of EOD is essentially asymmetric (flow rate and desalination effect depend on the current direction); this can afford operation with capacitive electrodes without commutation of diluate and concentrate streams.
- There are positive preliminary results concerning IEXM perforation (laser drilling and template molding); cheaper alternatives are explored.
- Experiments with composite materials are planned for near future.
- Partners are sought for the development of this new technological process.

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