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
Electrodialysis

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![Electrodialysis Diagram](image-url)
Electrodialysis: limiting current

\[ I_{\text{lim}} \approx \frac{F D_s c_0}{\delta \cdot (t_m - t_s)} \]
Electro-convection as a mechanism of over-limiting currents

Convection is a very effective salt-transport process yet tangential convection is often inefficient due to the no-slip condition at solid surfaces.
Electroosmosis is a preferred liquid-delivery tool in microfluidics because it is much more efficient at micro-scale than pressure-driven flows.

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

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.
Schematics of Electro-Osmo-Dialysis

- Cation exchange membrane
- Positively charged
- Flow
- Negatively charged
- Anion exchange membrane
- Current
Distribution of effective pressure within nanoporous medium

Flow rate is proportional to the gradient of effective pressure

hole radius 1 µm

$P(r,z)$
Distribution of concentration and flow streamlines within nano-porous layer

\[ \zeta = 50 \text{ mV} \]
Establishment of 1D distributions across nanoporous layer

\[ \Delta \varphi = 300 \text{ mV} \]
Establishment of 1D distributions across nanoporous layer

\[
\frac{\text{interhole distance}}{\text{layer thickness}} = 1
\]
Desalting vs applied voltage

\[ \zeta = 25 \text{ mV} \]
Current-voltage characteristics

\[ c_0 = 1 \text{ mM} \]
Specific energy consumption in desalination of brackish water

![Graph showing specific energy consumption as a function of voltage for different interhole distances and layer thicknesses. The graph includes data points for 0.1, 0.4, and 2 interhole distances and layer thicknesses, with a trend line indicating an increase in specific energy consumption with voltage.

2000 ppm NaCl]
Perforation scenarios: laser drilling
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.
THANK YOU FOR YOUR ATTENTION!