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Finite Element Analysis of Nanopores in Capacitive Energy Extraction Based on Double Layer Expansion (CDLE)

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Capacitive energy extraction based on double layer expansion (CDLE) is a new method devised for extracting energy from the exchange of fresh and salty water in porous electrodes. First suggested by D. Brogioli, it is enclosed in a group of emergent technologies jointly known as Capmix methods. The CDLE technique is based on the fact that the capacitance of the electric double layer (EDL) strongly depends on the ionic contents of the medium. If a metal/solution interface is externally charged in the presence of high ionic strength, and discharged in low ionic strength, it might be possible to obtain a net amount of energy. In order to increase the charge transfer, electrodes made of micro- or nano-porous carbon particles can be used because of their huge surface area.

The behaviour of the fluid flow field, the electric potential field and the ionic distributions inside the nanopores during an entire CDLE cycle must be correctly determined to gain a complete understanding of the physics involved and to optimize the energy extraction per cycle. We have performed a finite element analysis that computes the time-dependent full coupling between the Navier-Stokes, the Poisson and the mass transport (diffusion, convection and electromigration of ions) equations. From the numerical solutions, we have been able to obtain the relevant time scales of the processes that take place inside the nanopores and to compare them with experimental results.

As an example, the figure shows the time evolution of the ionic sodium concentration in a representative pore just after exchanging the solution in contact with the pore mouth from sea water to river water. Note that the expansion of the EDL has started in the region close to the mouth of the nanopore and that it is extending towards its interior.

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