Effective 1D models of electrokinetic flow through a microchannel with an ion-selective nanoporous end-plug

Christoffer Peder Nielsen, Mathias Bækbo Andersen, and Henrik Bruus
Department of Micro- and Nanotechnology, Technical University of Denmark

We present an analysis of the charge transfer in electrolytes flowing through microchannels with charged walls and equipped with an ion-selective nanoporous end-plug allowing passage of only the positive ions. As the voltage bias is increased from zero, a gradient develops in the concentration for both positive and negative ions such that the diffusion and electromigration current of the negative ions add to zero, while maintaining overall charge neutrality. At a sufficiently high voltage bias, the ion concentration reaches zero just in front of the nanoporous end-plug, a situation denoted the overlimiting current state. For even higher voltages, a highly non-linear state develops with a polarization charge region in front of the end-plug with no negative ions and a low concentration of positive ions.

In this work analyze the charge transport in terms of a simple 1D model, by averaging the Nernst-Planck equation across the channel and by assuming a Debye wall-charge screening layer much thinner than the channel width. Moreover, we allow for dynamic charge transfer between the wall charges and the electrolyte. In this combined model we find that the current saturates as function of the voltage bias. This contrasts predictions in the literature of a linearly growing current in the overlimiting regime, when the wall charge is assumed fixed without any dynamics.