Predicting streaming potentials generation in porous media with effective excess charge, comparison of numerical and analytical approaches

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The self-potential (SP) method attracts an increasing interest in hydrology and critical zone studies because of its non-invasive nature and its sensitivity to water flow and transport processes in the subsurface. The contribution to the SP signal by water flux is referred to as the streaming potential. It is due to the presence of an electrical double layer at the mineral-pore water interface. When water flows through the pore, it gives rise to a streaming current and a resulting measurable electrical voltage. Several approaches can be used to predict streaming potentials in saturated and partially saturated porous media. One approach conceptualizes the porous media as a capillary bundle and proposes a flux-averaging upscaling procedure to determine an excess charge which is effectively dragged in the medium by the water flow. The use of the latter has emerged during the last decades and is particularly relevant in hydrology as it directly relates this coupling parameter to existing transport properties. In this communication, we present and compare recent advances on how to determine the effective excess charge density from both analytical and numerical approaches. The analytical approach is a closed-form equation obtained by following the flux-averaging procedure on a fractal distribution of capillaries (for both saturated and partially water saturated porous media). This closed-form equation shows an explicit link between effective excess charge and the porous medium properties: petrophysical properties (porosity, permeability, hydraulic tortuosity) and interface chemistry properties (ionic concentration, zeta-potential). The numerical approach relies on 2D pore network simulations based on the electrokinetic coupling coefficient framework. Conducting these simulations on different well-controlled pore size distributions provided new data and helped to study the effect of pore size distributions upon streaming current generation. These simulations were performed for a large range of permeability (from 10^{-16} to 3×10^{-10} m^2) and ionic concentrations (from 10^{-4} to 1 mol L^{-1}). Our results show that the pore size distribution has a limited influence on the coupling coefficient for ionic concentrations smaller than 10^{-3} mol L^{-1}, while it completely drives the behavior of the effective excess charge density over several orders of magnitude. Comparing the analytical and numerical approaches, we show that the closed-form equation predicts very well the effective excess charge density for all the tested pore size distributions within its intrinsic limitations, that is, for a thin electrical double layer compared to the pore size.