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Predicting the streaming potential generation using the effective excess charge approach: a physically-based analytical model for saturated porous media

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The use of the streaming potential as a groundwater flow sensor is attracting an increasing interest for environmental studies. The generation of the streaming potential results from the presence of an electrical double layer at the mineral-pore water interface: when groundwater flows through the pore space, it gives rise to a streaming current and a resulting measurable electrical voltage. Alternatively to the use of the Helmholtz-Smoluchowski coupling coefficient, predicting the streaming potentials generation in saturated porous media can also be done by upscaling the excess charge which is effectively dragged in the medium by the water flow. Following a recent theoretical framework, we developed a physically-based analytical model to predict the effective excess charge density in saturated porous media where porous media are described by bundles of capillary tubes with fractal pore-size distribution. First, an analytical relationship is derived to determine the effective excess charge for a single capillary tube as a function of the pore water salinity. Then, this relationship is used to obtain both exact and approximated expressions for the effective excess charge at the Representative Elementary Volume (REV) scale. The resulting analytical relationship allows the determination of the effective excess charge as a function of pore water salinity and hydraulic parameters like porosity, permeability, and tortuosity. This new model has been successfully tested against data from the literature of different sources. One of the findings of this study is that it provides a mechanistic explanation to the empirical dependence between the effective excess charge and the permeability that has been found by various researchers. The proposed petrophysical relationship also contributes in better understanding the role of porosity and water salinity on effective excess charge and will help to push further the use of streaming potential to monitor groundwater flow.