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Streaming potential monitoring in partially saturated conditions: study of drainage and imbibition cycles in a sand column

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The self-potential (SP) method has attracted increasing interest in vadose zone hydrology and the soil sciences because of its non-invasive nature and sensitivity to flow and transport. Electrokinetic behaviour of porous media under two-phase flow conditions has been the subject of numerous publications. Such publications display diverging views on the origin of the SP response and on how to best model SP signals. One view focuses on the role of excess charge, dragged in the medium by the water flow, and how it evolves with saturation. The excess charge is then combined with well-known effects related to the unsaturated hydraulic and electrical conductivity. We recently developed a theoretical framework to predict the flux-averaged effective excess charge, as opposed to using the volumetric average as in most previous models. The corresponding relationship is derived using an analogy between porous media and bundles of capillary tubes, with properties inferred from either the water retention or the relative permeability function. Streaming potentials predicted using this model provide a better match to experimental data than previous models. Our work leads to a pretty interesting observation concerning the hysteretic behavior of the effective excess charge function. To further test our model and that specific observation, we have conducted well-controlled drainage and imbibition experiments at the laboratory scale. We used a 1.5 m sand-filled column in which we monitored SP (17 electrodes), pressure (10 tensiometers), and mass, together with the temperature and the relative humidity of the laboratory. Repeated cycles of drainage and imbibition spanning a saturation range from 30% to 100% resulted in high-quality SP signals (up to 15 mV). Given the fact the measurements were conducted over 6 months, the raw experimental results had to be processed to remove room temperature changes. We have modeled our experiments with a finite-element code based on our current understanding of electrokinetic theory. We find that there is a good agreement between experimental and numerical results. This approach to streaming potential modeling will be used in the future to interpret field-scale SP monitoring data in the vadose zone in terms of aquifer recharge at an agricultural field site.