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Characterization of electrokinetic coupling in porous media during oil-brine flow

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We have used a simple conceptual bundle of capillary tubes model, and streaming potential measurements on sandstone cores, to characterize electrokinetic coupling during the flow of water and an immiscible second phase such as oil. We demonstrate that the streaming potential coupling coefficient depends on the pore-scale distribution of the fluid phases, and the pore-scale distribution of excess charge associated with the electrical double layer. This in turn depends on the pore-space topology and the wetting behaviour of the solid surfaces.

When water is the wetting phase, and the second phase is non-polar and does not contain an excess of charge, the capillary tubes model predicts that the relative coupling coefficient decreases monotonically with decreasing water saturation, falling to zero at the irreducible water saturation when water flow ceases. Experimental data obtained from unsteady-state drainage experiments, with oil displacing water, are qualitatively similar to the model predictions; however, the decrease in coupling coefficient is non-monotonic, and the relatively coupling coefficient remains well above zero at water saturations very close to irreducible.

We hypothesize that water flow in thin wetting layers is responsible for the surprisingly large electrokinetic coupling observed at low water saturation. Wetting layer flow is not captured in the capillary tubes model, which may explain the discrepancy between prediction and observation. The non-monotonic decrease in relative coupling coefficient observed in the experimental data reflects the pore-scale distribution of the fluid phases and excess charge. If the streaming current is less affected than the electrical conductivity by the decrease in water saturation, the relative coupling coefficient can increase rather than decrease. The very simple pore-space topology of the capillary-tubes model fails to capture this behaviour.

If oil is the wetting phase but is non-polar, the capillary tubes model predicts that the relative coupling coefficient increases with decreasing water saturation, before falling sharply to zero at the irreducible water saturation. If both phases are polar and contain an excess of charge, the model predicts that the relative coupling coefficient may change sign and/or be significantly enhanced at partial saturation. We are currently undertaking experiments to investigate the validity of these predictions.