The salinity dependence of SIP parameters studied with an extended model of membrane polarization

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Introduction

An important parameter influencing the behaviour of induced polarization (IP) spectra is fluid salinity. Scott et al. (2004) observed that the phase shift may either increase or decrease with increasing salinity. Slater and Glaser (2003) and Kruschwitz et al. (2010) investigated the imaginary conductivity (around 1 Hz) and found an increase with fluid salinity. In order to understand the behaviour of SIP spectra from a mechanistic point of view, we carried out numerical simulations with a new model of membrane polarization (Bücker and Hördt 2013). We discuss the results in the context of previously published experimental observations.

The model

In the original membrane polarization model by Marshall and Madden (1959), the IP effect is caused by different mobilities in two one-dimensional pore types. Assuming that the (apparent) mobility variation is related to the electrical double layer (EDL), Bücker and Hördt (2013) expand the model to a two-dimensional system with finite pore size (Fig. 1). The model is defined by the geometrical parameters r_1, r_2, L_1 and L_2, the ion mobilities, the Zeta potential, the partition factor, and the parameters controlling the Debye length. The salinity influences the impedance as a constant factor, and through the definition of the EDL thickness.

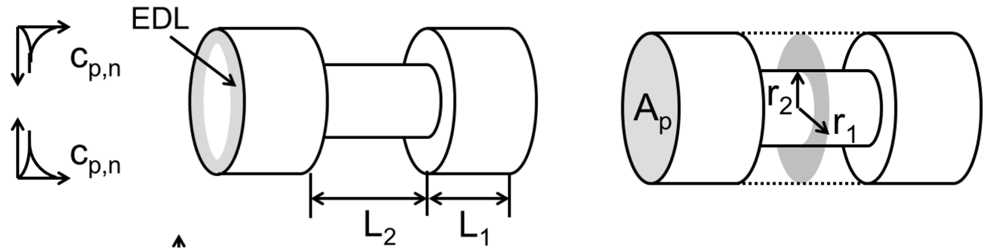

Fig.1: Extended model to simulate membrane polarization. Left: Definition of pore lengths and schematic behaviour of anion and cation concentration c_p and c_n with distance from the pore surface within the EDL. Right: Definition of the two pore radii (after Bücker and Hördt 2013).

Results

The extended Marshall-Madden impedance was calculated as function of ion concentration, for fixed pore lengths and different combinations of pore radii (Fig. 2). The maximum phase shift (left panel) was determined from the spectra as a measure of the IP effect. It first increases, and then decreases with increasing salinity, where the peak salinity depends on the pore radii. This observation is qualitatively consistent with experimental results obtained by Scott et al. (2004), who observed that "…decreasing the salinity … can cause the phase angle to either decrease or increase, depending on the sandstone".

The imaginary conductivity increases with fluid salinity for the parameter range (frequencies and pore radii) investigated here (Fig. 2, right panel). This trend can also be observed in experimental data (e.g. Slater and Glaser 2003; Weller et al. 2011). However, Weller et al. (2011) also find a decrease of imaginary conductivity at high salinities for some of their samples, which is not visible in our simulated results.

The relaxation times obtained with our model (not shown here) are fairly independent of salinity, consistent with experimental observations.

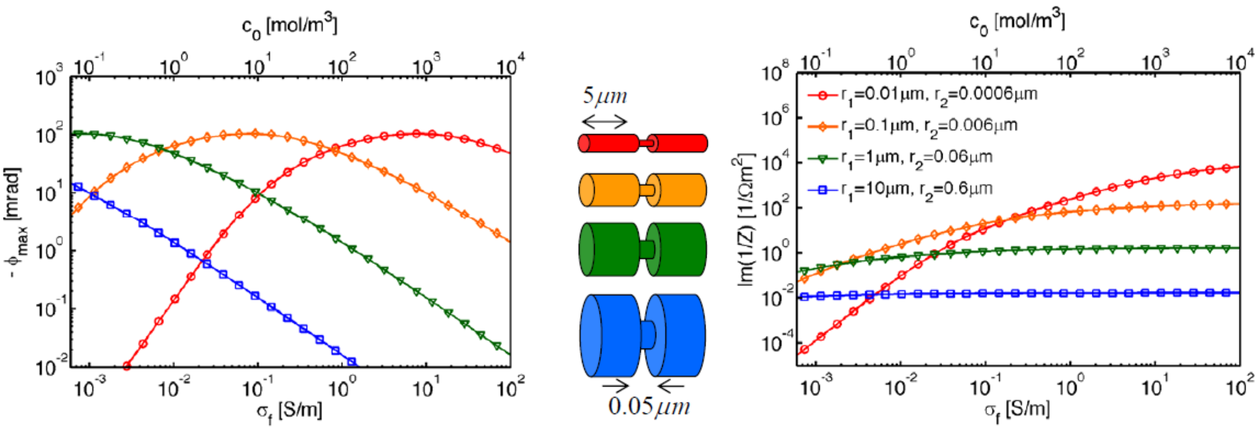

Fig. 2: Simulated phase shift (left) and imaginary conductivity (right) vs. fluid conductivity for different pore radii. The middle section illustrates the models (not to scale), where the pore lengths are constant.

Conclusions

We use an extended model of membrane polarization that explicitly includes pore radii and the EDL to simulate the influence of fluid conductivity on SIP spectra. The model is able to reproduce general trends observed experimentally, such as both decreasing and increasing phase shifts, and increasing imaginary conductivity. Some specific features of measured data, such as an increase of imaginary conductivity at high salinities, were not yet reproduced.

References

Bücker, M. and Hördt, A., 2013. Analytical modelling of membrane polarization with explicit parametrization of pore radii and the electrical double layer. *Geophys. J. Int.*, *in press*.

Kruschwitz, S., Binley, A., Lesmes, D. and Elshenawy, A., 2010. Textural controls on low-frequency electrical spectra of porous media. *Geophysics*, 75, WA113-WA123.

Marshall, D. and Madden, T., 1959. Induced polarization, a study of its causes. *Geophysics*, 24(4), 790-816.

Scott, J., Weller, A., Schleifer, N. and Barker, R., 2004. The effect of changing the salinity of the groundwater on SIP of sandstones. *10th Eur. Meeting Env. Eng. Geoph.*

Slater, L.D. and Glaser, D.R., 2003. Controls on induced polarization in sandy unconsolidated sediments and application to aquifer characterization. *Geophysics*, 68, 1547-1588.

Weller, A., Breede, K., Slater, L. and Nordsiek, S., 2011. Effect of changing water salinity on complex conductivity spectra of sandstones. *Geophysics*, 76, F315-F327.