

Experimental and theoretical studies of the temperature dependence of spectral induced polarization (SIP) based on a membrane polarization model

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Introduction

Knowing the temperature dependence of spectral induced polarization is essential for applications, where temperature changes, like seasonal variations or spatial variations at geothermal sites, are expected. The knowledge is also useful for comparing field and laboratory measurements and may help to understand the polarization mechanisms at the pore scale. Previous investigations indicated that the influence of temperature variation on the phase shift is not dramatic (e.g. Binley et al. 2010), but if we are interested in a wide temperature range and/or very precise measurements, temperature effects have to be considered. We compare the temperature dependence of SIP-parameters from measurements on several samples to calculations with an extended membrane polarization model.

Membrane polarization model

The membrane polarization model we use in this study is based on the one-dimensional equations developed by Marshall and Madden (1959). They study the movement of the ions through active and passive zones, which represent the narrow and wide pores, characterized by different mobilities of cations and anions. This model was extended by Bucker and Hördt (2013) to the description of the pores as cylinders of two different lengths (L_1 and L_2) and radii (r_1 and r_2). The ions moving through these pores are influenced by the electrical double layer, leading to a gradient of ion concentration along the pore.

Ion diffusion coefficients, Debye length, and Zeta-Potential, obviously vary with temperature. Ion mobility and Debye length are also affected by the temperature dependence of dynamic viscosity and relative electrical permittivity, which can be described by empirical equations.

The phase shift was calculated for different pore lengths and radii. Figure 1 shows that a variation of the pore radii lets the highest phase values (deep red colours) appear at higher temperatures and slightly higher frequencies. Decreasing the pore radii shifts the highest phase values towards lower temperatures, whereas increasing the radii shifts them towards higher temperatures. The magnitude of the highest phase values slightly changes.

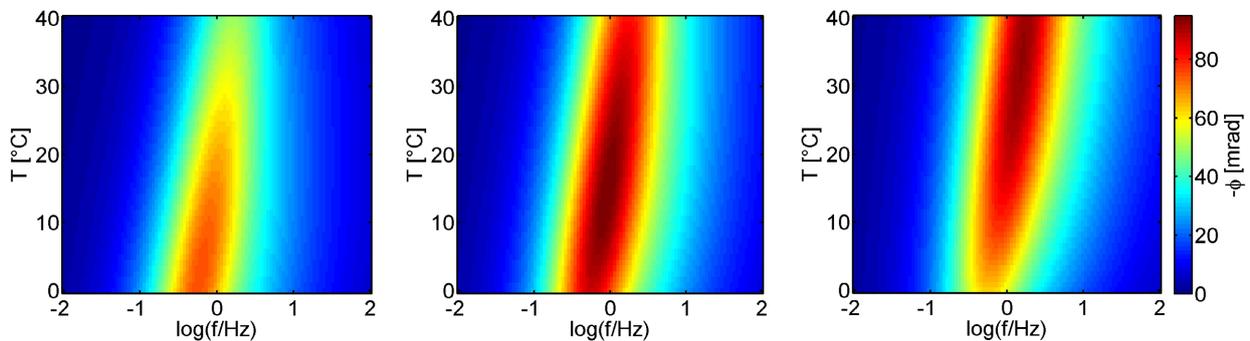


Fig. 1: Phase shift colour coded as function of frequency and temperature calculated with the model of Bucker and Hördt (2013) for different pore radii increasing from left to right. Left: $r_1 = 0.155 \mu\text{m}$, $r_2 = 0.009 \mu\text{m}$. Middle: $r_1 = 0.31 \mu\text{m}$, $r_2 = 0.018 \mu\text{m}$. Right: $r_1 = 0.62 \mu\text{m}$, $r_2 = 0.036 \mu\text{m}$. Pore lengths are $L_1 = 50 \mu\text{m}$, $L_2 = 0.5 \mu\text{m}$.

Measurements

Measurements were performed on several sandstones, limestones, and argillites. The samples were fully saturated with a sodium chloride solution, which had an electrical conductivity of 55 mS m^{-1} . The temperature was increased in steps of $5 \text{ }^\circ\text{C}$.

As an example, the temperature dependence of the phase shift of two sandstone samples in the temperature range of 0 to $40 \text{ }^\circ\text{C}$ is shown in Fig. 2. The phase shift of sample OK1 (Fig. 2, left) increases with temperature, whereas the phase shift of sample P8 (Fig. 2, right) decreases with temperature. We also note a shift of the maximum phase towards higher frequencies with increasing temperature.

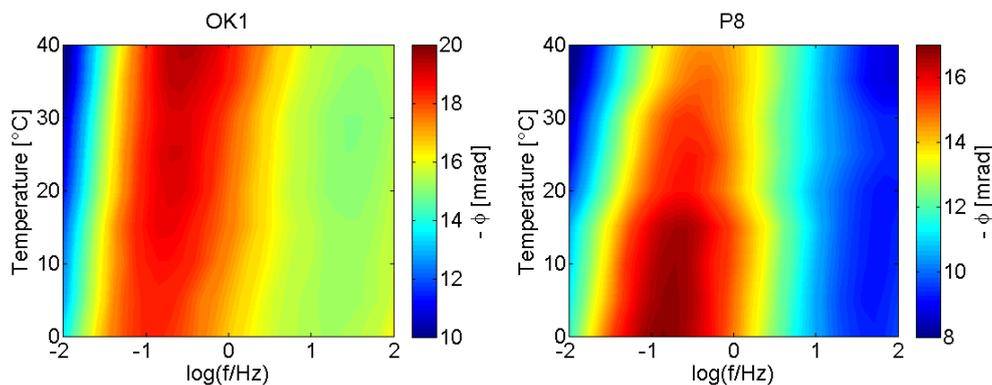


Fig. 2: Measured phase shift of two different sandstone samples OK1 (left) and P8 (right) as a function of frequency and temperature. Note that the colour scales are different.

Conclusions

Measured and calculated phase spectra show a qualitatively similar temperature dependence, indicating that our simple model can in principle simulate the polarization effects. Our modelling results show that the location of the highest phase values depends on the pore size, suggesting that the pore size may be important for the differences in the temperature dependence of the measured samples. Future analysis of the pore size distributions of the samples will provide additional information about the samples and might help to compare measurements and model results.

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