Spectral induced polarization monitoring of CO_2 injection in saturated sands: laboratory experiment and modelling

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During the last decade, the interest of induced polarization methods for environmental studies has undoubtedly grown. Here, we present a set of laboratory experiments aimed at assessing the ability of spectral induced polarization (SIP) method to detect and monitor CO_2 transfers in the subsurface. The objectives were the quantification of the influence of various parameters on the SIP response, such as the water conductivity, the chemical reactivity of the solid and of the gas phases, and the injection rate. SIP measurements in the frequency range 50 mHz – 20 kHz were thus performed during gas (N_2 or CO_2) injections in a metric-scaled, cylindrical tank filled with unconsolidated granular material (quartz or carbonate sands) and fully saturated with water (Fig. 1).

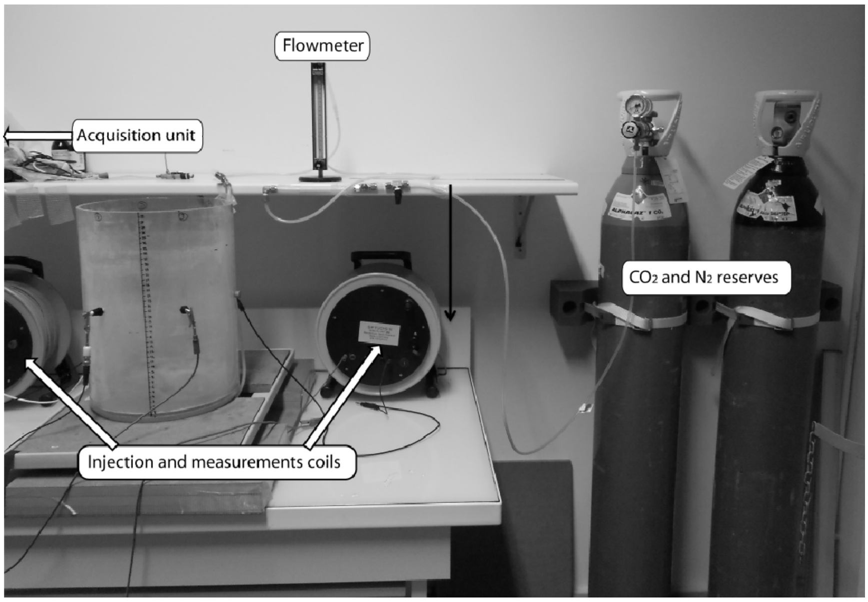

Fig. 1: Experimental set-up.

The system was most reactive to gas injection in the high frequency range (> 1 kHz). In quartz sand, the presence of gas in the medium tends to decrease the measured values of the phase angle. This effect becomes more important when increasing the injection rate, and thus the amount of gas trapped in the medium. The magnitude of this effect decreases when the water conductivity increases.

Dissolution processes (CO_2 in water and also solid matrix in the case of carbonated sand) were evidenced from chemical measurements (pH, conductivity and anionic concentrations). The increased ionic strength resulted in a decrease of the bulk resistivity and in an increase of the phase values at high frequency (Fig. 2). An interesting parameter is the ratio of the increase in phase to the decrease in resistivity. When dissolution processes are involved, this ratio increases strongly with the initial conductivity of the saturating fluid. Hence, in some cases the measured phase values still bring measurable information on the system evolution even if resistivity variations are very small.

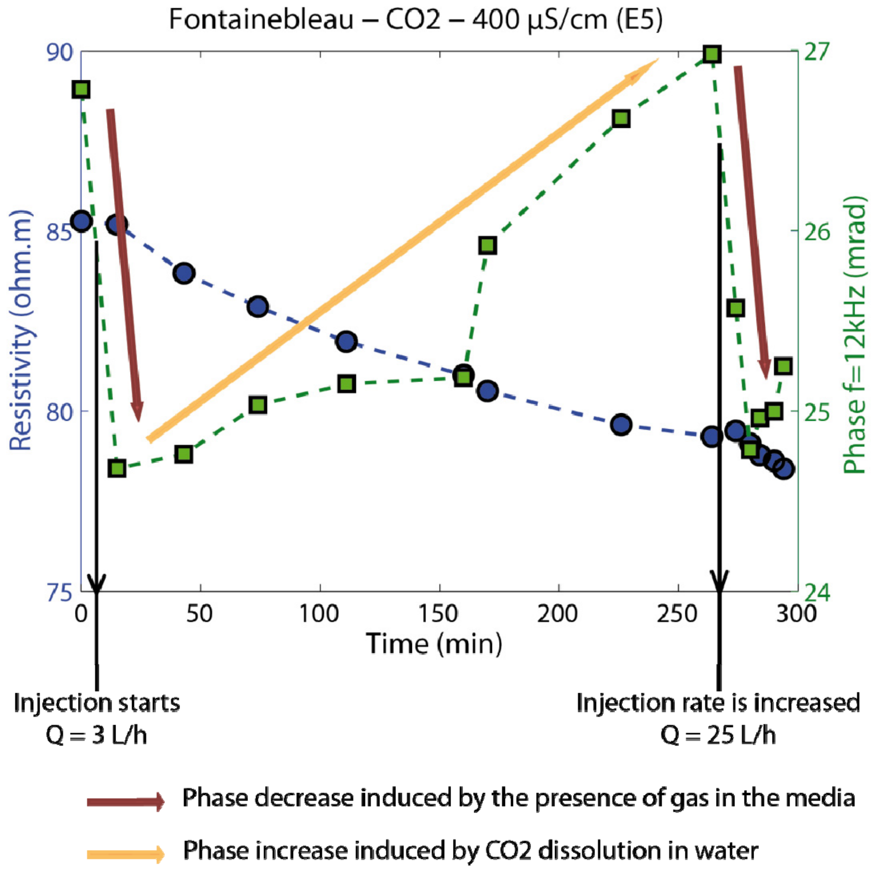

Fig. 2: Temporal evolution of the resistivity and the phase angle at the frequency 12 kHz for the experiment E5 (CO_2 injection in a Fontainebleau sand saturated with a 400µS cm^{-1} conductivity water). We can observe the effect of both gas invasion (red arrows – phase decrease) and CO_2 dissolution (yellow arrow – phase increase). Resistivity changes are less significant.

We were able to model these experiments using the numerical simulation code FEHM (Viswanathan et al. 2012), designed at the Los Alamos National Laboratory. Saturation evolution, CO_2 and carbonate dissolution, and dissolved species diffusion were described. We propose a theoretical framework to describe the high frequency behaviour of the SIP response in the high frequency range (100 Hz – 20 kHz). This theoretical model fits with the experimental data, and depends on the amount of ionic species present in the saturating water and the saturation state of the porous media.

References

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