



Estimation of the electrical potential distribution along metallic casing from surface self-potential profile

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ABSTRACT

Corroding casings of wells generate negative self-potential (SP) anomalies, increasing from about -10 to -500 mV in the vicinity of the well to 0 mV at large distances. As reported in previous laboratory experiment, SP can be used to retrieve the distribution of electrical potential along the casing, which is somehow a proxy for the corrosion state of the casing. These studies used 3D (whole space) or surface 2D (whole surface) measurements of SP distribution; here we reported a field example, for which only a 1D surface SP profile is available. In order to retrieve the most probable associated potential distribution (defined by a spline) along the 11.1-m long metallic casing, we develop a direct model based on geometrical and geoelectrical properties of the medium, which was then used in a (non-deterministic) optimization procedure by simulated annealing, including some physical constrains. Tests carried out on a synthetic case allowed the initial source to be correctly retrieved, provided that the number of nodes used for the spline defining the potential distribution along the casing is large enough. The inversion of real field data provided a dipolar anomaly, with minimal negative amplitude of around -600 mV at 5 m, and maximal positive amplitude of about 1100 mV at 9 m (close to the level of the water table), this shape being in agreement with the results of previous laboratory studies.

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1. Introduction

The self-potential (SP) method, which consists in measuring the natural electrical potential, has been applied for the characterization of fluid circulation in the subsurface since the 1970's. Indeed, due to the electrokinetic effect, the movement of electrolyte through porous media generates a local electric field, generally oriented along the opposite of the flow direction. Recording the electrical potential at the surface therefore provides information about the water movement, such as its direction and amplitude. The method presents the advantage of being low-cost, easy to implement in the field, and to allow the site to be investigated with a dense spatial sampling (and even temporal one if time-lapse measurements are required). The potential difference is simply measured between two unpolarisable electrodes (Petiau and Dupis 1980; Petiau 2000) placed at the surface of the ground, possibly with bentonite saturated with brine to ensure a good electrical contact with the soil. The reference electrode is kept fixed far from the considered zone of expected SP anomaly, whereas the measuring electrode is moved to each measurement point, in order to obtain profiles or maps. As the expected values of the potential generally range between 5 and 100 mV, the potential difference is measured with an ohmmeter with high entrance impedance.

Numerous studies have been published during the two last decades about the use of the SP method for hydrological purposes (see for instance the reviews by Bolève et al. 2007; Jouniaux et al. 2009; Revil et al. 2012 and references therein). In particular, the SP method gave excellent results when applied to pumping tests. In this case, the SP profiles are anticorrelated with the drawdown, as observed in laboratory experiments (e.g., Suski et al. 2004) or in the field (e.g., Bogoslovsky and Ogilvy 1973; Rizzo et al. 2004), allowing the aquifer properties, such as transmissivity, to be retrieved using different algorithms (e.g., Patella 1997; Darnet et al. 2003; Revil et al. 2003; Titov et al. 2005). However, in the field, the electrokinetic signal of interest can be masked by additional potentials, in particular when the well casing is metallic. In this case, the casing may act as an electronic conductor between the oxidizing upper part of the subsurface, enriched in oxygen, and the reducing, depleted deeper part. This system, acting as a half-generator, is known as the geobattery (Sato and Mooney 1960; Stoll et al. 1995; Bigalke and Grabner 1997): the upper part of the metallic conductor plays the role of the cathode, with reduction reactions, and is therefore negatively charged, whereas the lower one is the positively charged anode, with oxidation reactions; electrons flow through the metallic body and outside it ionic currents close the circuit. The resulting anomaly at the surface is negative, with amplitude that can reach more than 500 mV. This mechanism has been successfully applied to explain the SP anomaly observed near the KTB deep well and resulting from the existence of graphitic dykes (Bigalke and Grabner 1997). Moreover, the signal can evolve with time, when corrosion phenomena develop

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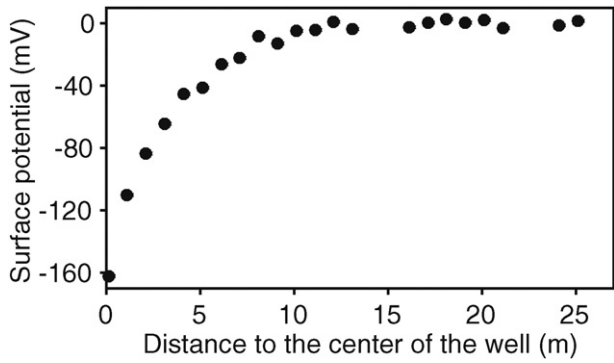


Fig. 1. Self-potential profile measured at the surface in the vicinity of the piezometer. Note that data were reduced from the mean value computed over the last eight points, in order to set the potential differences equal to zero far from the source.

(e.g., Castermant et al. 2008; Rittgers et al. 2013). When measuring SP potential during pumping tests in the case of metallic casing, the anomaly resulting from the fluid flow can be obtained by subtracting the SP values measured before the test (i.e., resulting uniquely from the geobattery effect).

Here we reported a case for which this initial correction cannot be applied. Our primary goal was to evaluate the ability of the SP method to detect and even characterize the fluid circulation in an In-Situ-Recovery (ISR) cell. ISR is a technique used to extract soluble ore by injecting solvent in one or more well and pumping it in recovery wells. Examination of the SP map and profiles evidenced that the predominant component of the signal was due to corrosion effect. But since it is almost impossible to stop an already functioning ISR cell, the correction described above was not applicable. Moreover, even if the production could be stopped, solvents remaining in the medium could have an effect on the SP signal, which will be added

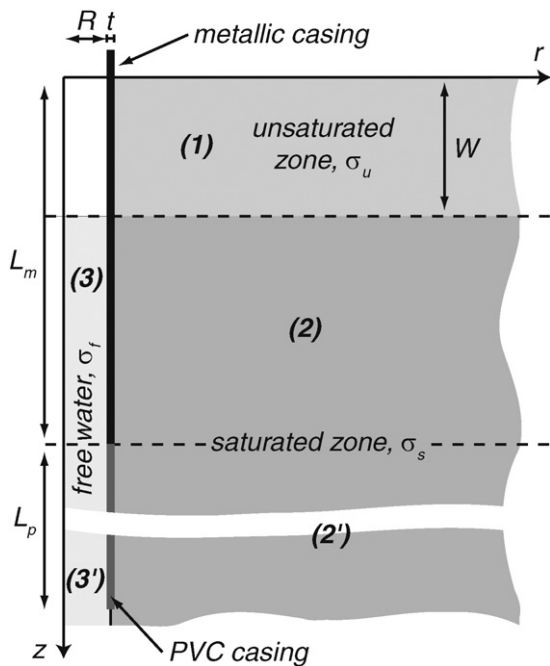


Fig. 2. Model of the medium (radially symmetric). An unsaturated zone of electrical conductivity σ_u and thickness W covers a zone of conductivity σ_s saturated with a fluid of conductivity σ_f . The well of internal radius R has a metallic casing of thickness t until the depth L_m , then an impervious PVC casing until the depth $L_m + L_p$.

to the pure corrosion signal. The problem here was that we have no “zero state” SP signals to perform the correction.

However, a piezometer with similar casing is located near the cell, far enough for not being influenced by the fluid circulation. The SP profile shown in Fig. 1 exhibits a negative anomaly, reaching about -160 mV close to the casing, and returning to zero at around 15 m. The shape is very similar to those reported by Castermant et al. (2008) in a laboratory experiment in which a metallic rod was set free to corrode in a tank filled with saturated sand. The idea was to use the SP profile from the piezometer to correct the observed SP anomaly on the ISR cell. In theory, from previous laboratory experiments, the potential at the surface resulting from the corrosion of the well casing can be modelled (e.g., Castermant et al. 2008), provided that information about the properties of the constituents of the casing and the chemistry of the medium, such as pH and redox potential distributions, are known. Unfortunately, in the field we did not have this information.

If direct modelling is not possible, inversion of SP can be performed. In the previous laboratory studies published in the literature (Castermant et al. 2008; Rittgers et al. 2013), retrieval of potential along the casing was performed from 3D (whole space) or 2D (whole surface) measurements of SP, using deterministic algorithms. In our case, we only have a 1D surface profile: the problem is largely badly constrained. That is the reason why we develop a non-deterministic inversion procedure to estimate the most probable electrical potential distribution along the well casing. The casing is considered as the unique source of SP signals and no a priori about the underlying chemical phenomena is required.

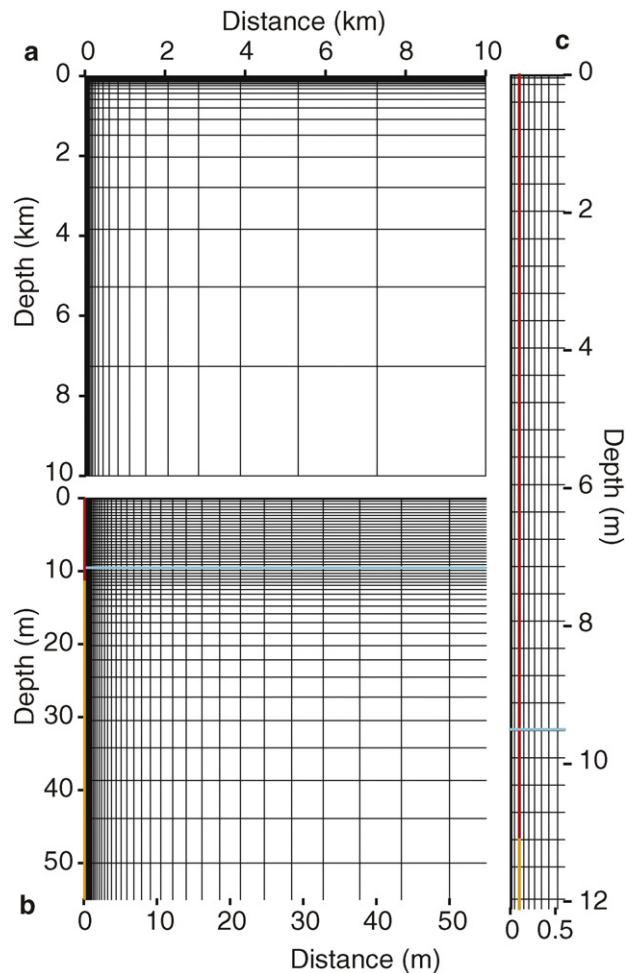


Fig. 3. Representation of the grid (irregular, rectangular mesh). a) large scale, b) domain of interest, c) near the well.

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