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On baseline determination and gas saturation derivation from downhole electrical monitoring of shallow biogenic gas production

Philippe A. Pezard[a], Halidi Abdoulghafour[a], Nataliya Denchik[a,]*, Hervé Perroud[a], Johanna Lofi[a], Florent Brondolo[a], Gilles Henry[a] and Denis Neyens[b]

[a] *Géosciences Montpellier - CNRS (UMR 5243), Université de Montpellier 2, Place Eugène Bataillon, 34095 Montpellier Cedex 05, France*
[b] *imaGeau, Cap Alpha, 9 avenue de l'Europe, Clapiers, France*

Abstract

Adequate hydrogeophysical monitoring of CO_2 geological storage remains a challenge as different parameters might be modified during storage. That implies to compare real-time measurements to an adequate baseline. At the Maguelone shallow experimental site a representative baseline for electrical resistivity was built from a large number of downhole geophysical measurements. At this coastal site this issue is particularly important due to the production of biogenic gas from the subsurface sediments. For this, a modified petrophysical model based on the Waxman-Smits model is proposed to estimate gas saturation found to vary from 2 to 7% within shallow sand layers.

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Keywords: baseline; CO_2; biogenic gas; monitoring; petrophysical model

1. Introduction

The controllability and reliability of the CCS operations require precise monitoring of reservoir fluid and geophysical properties, either before or during CO_2 injection, and also in the long run to control storage stability over time. In this context, access to deep saline aquifers data from geophysical and chemical monitoring systems

* Nataliya Denchik. Tel.: +33-467-149-309; fax: +33-467-143-642.
E-mail address: nataliya.denchik@gm.univ-montp2.fr

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constitutes an important challenge preceding any industrial deployment. Therefore, controllable shallow depth injection provides a means to study at small scale and thereby reasonable cost the response of saline reservoirs during and after CO_2 injection.

Understanding the potential impact of CO_2 migration into shallow groundwater systems requires the development of an adequate monitoring strategy to follow gas plume dynamics and possible geochemical changes in the subsurface. The monitoring methods usually deployed combined surface deployment for large scale assessments, and downhole methods for near-field and more precise boundary conditions recording. Either at surface or downhole, hydrological, geophysical, mechanical and geochemical parameters are recorded to follow the complex processes associated with gas injection and long-term storage. Recently, shallow field experiments conducted by Dafflon et al. [1], Denchik et al. [2], Spangler et al. [3] and Pezard et al. [4] (*submitted*), demonstrate the feasibility of shallow gas injection and CO_2 plume propagation monitoring over time. In particular, these studies explore the sensitivity of time lapse resistivity measurements to gas injection and long-term storage. For instance, Denchik et al. [2] and Pezard et al. [4] show at the Svelvik (Norway) and Maguelone (Languedoc, France) sites, respectively, how a set of coordinated monitoring methods responds to gas injection (either N_2 or CO_2), inducing changes to host formation physical and chemical properties.

For all methods, adequate monitoring requires the determination of a baseline representative of the site dedicated to long-term CO_2 storage (Jones et al. [5]). This baseline cannot just be the average of measurements made over the few days preceding the injection. The Maguelone shallow experimental site provides the opportunity to study the accuracy of hydrogeophysical monitoring methods. The geology, petrophysical framework and hydrology of this site have been studied in details in previous studies, revealing the presence of a thin saline aquifer at 13-16 m depth surrounded by impermeable clay-rich materials. The monitoring setup is composed of a series of hydrogeophysical and geochemical methods, offering measurements of fluid pore pressure, electrical resistivity, acoustic velocities as well as pH and fluid properties including chemistry. After a series of gas injection experiments at the Maguelone site conducted, for the latest, in January 2013 [4], fluctuations overtime of reservoir fluids chemistry and properties (such as pore fluid pH) were in fact observed after steady state conditions were restored, demonstrating the natural variability of the site in terms of biogenic gas (such as H_2S, CH_4, CO_2) production and transfer from the sedimentary pile toward the surface.

This study is aimed to assess the response of the reservoir during CO_2 injection, by quantifying the produced natural gas and its transfer between the main reservoir located about 15 m depth and a secondary storage reservoir located at 8 m depth. To achieve a representative monitoring of gas storage and flow in the subsurface, all measurements need to be compared to a representative baseline, constructed for all geophysical and geochemical data recorded from surface and downhole observatories. In order to achieve this objective, high frequency measurements were made months after any gas injection at the site. This paper focuses on high frequency logging of electrical properties constrained with several geophysical and geochemical measurements covering the 20 m depth where the targeted saline aquifers are surrounded by clay-rich materials.

2. Experimental setup

2.1. Site characteristics

The Maguelone experimental site has been described in great details in geological, petrophysical and hydrogeological terms (Lofi et al. [6], Pezard et al. [4]).

In brief, the experimental site (Fig. 1) for gas injection hydrogeophysical and geochemical monitoring is constituted with two main saline aquifers located, respectively, between 8 and 9 m depth for the shallower one, and between 13 to 16 m depth for the deeper one (Fig. 2). The shallow reservoir consists in lagoonal sandy sediments deposited in recent Holocene times and topped by impermeable argillaceous materials.

The deeper reservoir consists in porous and permeable layer made of polygenic gravels and pebbles variable in grain size, locally cemented. It is surrounded by clay and silt horizons above and dark organic-rich clay materials below (Fig. 2). The description of the geological setting is supported by downhole geophysical data (natural gamma, electrical resistivity and seismic velocity logs in each of the holes penetrating it). From a hydrological point of view, the electrical conductivity logs indicated that the sedimentary column is saturated with saline water (34 $g.l^{-1}$) to