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Monitoring Carbon Dioxide Saturation through Wireline Logging Techniques

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1- Introduction:

As a way to combat global warming, storage of carbon dioxide in saline aquifer is deemed to be one of the most effective mitigation options. As such, the CO_2Sink project has been carried out in Ketzin. The project is a R&D project, supported by the EU commission, targeted at developing an in situ laboratory for CO_2 storage. Its aims are to advance in the understanding of the processes involved in underground CO_2 storage and to provide operational experience to aid in the development of harmonized regulatory frameworks and standards for CO_2 geological storage.

Three wells: an injector and two observation wells spaced out at 50m and 100 m from the injector had been drilled in 2007 to a TD of 750m. Injection operations consist in injecting downhole 60, 000 tons of CO_2 during two years, has started in late June 2008. To achieve the main objectives of the projects that concern the storage performance, several monitoring techniques had been selected: 3D time lapse seismic, vertical seismic profiling (VSP), moving source profiling (MSP), distributed temperature sensing (DTS), vertical electrical resistivity array (VERA) and pulsed neutron logging. This logging technique that measures the macroscopic thermal capture cross-section Σ is widely used in the oilfield for cased-hole saturation monitoring, was selected because of the high formation water salinity, the high formation porosity along with a high contrast in Σ between saline formation water and CO_2.

The paper looks at the Reservoir Saturation Tool (RST*) data acquired in the observation well and illustrates how the CO_2 saturation was successfully measured.

2- Pulsed Neutron Measurement Principles:

Using a dual burst technique, a neutron generator in the RST* repeatedly emits pulses of high energy neutrons (Fig.1). Following each burst, the neutrons are quickly slowed down in the borehole and formation to thermal velocities. They are then captured by nuclei with a corresponding emission of gamma rays. Changes in the thermal neutron population in the media are sampled by gamma ray detectors placed at a short distance from the high energy pulsed neutron source. Σ, the macroscopic thermal neutron capture cross-section of the formation, is determined by analyzing the decline of gamma ray count rates with time as the neutrons are captured by surrounding materials (neutron capture) and as they diffuse farther away (neutron diffusion). Σ is inferred from this observed decline of gamma ray count rate versus time and is corrected for diffusion, borehole and lithology effects through the use of a database that includes over 1000 measured points augmented with 400 modeled points spanning different lithologies, porosities, borehole sizes, casing sizes and weights, formation salinities and borehole fluid salinities that are typically encountered in CCS operations.

3- Pulsed Neutron Interpretation:

Since Σ_{co2} has a value of 0.03 CU, knowing the formation water characteristics (Σ_w) and having a petrophysical formation evaluation (ϕ, V_{cl}, Σ_{cl}, Σ_{ma}), S_w the water saturation, can be derived from the following equation:

$$\Sigma_{log} = \phi g_w \Sigma_w + \phi\,(1- S_w) \quad \Sigma_{co2} + V_{cl} \quad \Sigma_{cl} + (1 - g\phi - V_{cl}) \quad \Sigma_{ma}$$

4- Application to Ketzin:

4.1: Baseline logs:

Immediately after the observation well was completed in 2007, a RST* baseline log was acquired in May 2007, with fresh water in the borehole. Due to the shallow RST* depth of investigation and the fresh borehole fluid invasion, it was decided to acquire another baseline in June 2008 with the borehole fluid the same as that of the original formation water (240 ppk). Fig. 2 shows the difference between the two baseline logs. With fresh water in the borehole, the 2007 baseline log exhibits a behavior similar to that of a formation filled with CO_2 since fresh water has a low value of Σ.

4.2 Breakthrough:

Breakthrough at the Ktz200 observation well, located 50 m from the injector occurred three weeks after the injection process had started as indicated by monitoring the well head pressure (16^{th} Jul. 2008). A RST was run five days later on July 21^{st} to monitor the water saturation. Fig.3 is a the result of the RST interpretation, where along side of the RST Σ, are also displayed the saturation curves for different CO_2 saturations. These curves are derived from the multi-minerals log analysis program using a fixed CO_2 saturation. Pink shading shows a decrease in Σ due to the presence of CO_2.

Although CO_2 is being injected through the two sandy intervals of similar characteristics, the breakthrough had occurred only at the upper sand. This is probably due to the presence of vertical fractures in the injector well, seen on the FMI image that had caused the upward CO_2 migration. CO_2 saturation in the upper sand is around 60%, very little CO_2 is present in the lower sand. This is probably due to the presence of a permeability barrier between the two wells or to a damaged zone. Unfortunately, in the absence of a PLT log, neither assumption could be confirmed.

Conclusions:

Thanks to the high formation water salinity, the high formation porosity along with a high contrast in Σ between saline formation water and CO_2, the CO_2 saturation was successfully measured in the KTZ200 observation well using the RST.

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Figure 1: : Comparison of RST baseline in Fresh Water (Blue) and Salt Satured Water (Red)

Figure 2: : $C0_2$ Saturation from RST log