Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 63 (2014) 5749 – 5753

Energy Procedia

GHGT-12

# 1:1 scale wellbore experiment and associated modeling for a better understanding of well integrity in the context of $CO_2$ geological storage

JC. Manceau[a]*, J. Trémosa[a], P. Audigane[a], F. Claret[a], L.J. Wasch[b], F. Gherardi[c], O. Ukelis[d], A. Dimier[d], C. Nussbaum[e], Y. Lettry[f], T. Fierz[f]

[a] *BRGM, 3 avenue C. Guillemin 45060 Orléans Cedex 2 France*
[b] *TNO, Princetonlaan 6, 3584 CB Utrecht, the Netherlands*
[c] *IGG-CNR, via G.Moruzzi, 1, 56124, Pisa, Italy*
[d] *EIFER, Emmy-Noether-Strasse 11, D-76131 Karlsruhe, Germany*
[e] *SWISSTOPO, Seftigenstrasse 264, 3084 Wabern, Switzerland*
[f] *SOLEXPERTS, Mettlenbachstr. 25, 8617 Mönchaltorf, Switzerland*

**Abstract**

In this study, we present a new experiment for following the evolution of the well integrity over time due to different changes in well conditions (pressure, temperature and fluids in contact with the well) in the context of CO2 geological storage. A small section of a wellbore is reproduced in the Opalinus Clay of the underground rock laboratory of Mont-Terri, Switzerland (caprock-like formation) at scale 1:1. This system has been characterized hydraulically and geochemically during three periods: initial state, after an increase in the well temperature and after replacing the fluid by pore water with dissolved CO2. The characterization of the system includes both performing hydro-tests to quantify the hydraulic properties of the well and their evolution over time, and sampling the fluids to analyze the geochemical composition and changes. The results presented in this study confirm the ability of the chosen design to estimate the evolution of the well integrity over time.


Peer-review under responsibility of the Organizing Committee of GHGT-12

*Keywords:* $CO_2$ geological storage; well bore integrity; underground rock laboratory

* Corresponding author. Tel.: +33-238644805; fax: +33-238644725.
*E-mail address:* jc.manceau@brgm.fr


Peer-review under responsibility of the Organizing Committee of GHGT-12
doi:10.1016/j.egypro.2014.11.607

## 1. Introduction

On a geological carbon dioxide storage site, wells (decommissioned or active) drilled through low-permeable caprock are potential connections between the $CO_2$ storage reservoir and overlying sensitive targets like aquifers. The integrity of wells over time is therefore essential for the fluids confinements (brine with or without dissolved $CO_2$ or buoyant gaseous $CO_2$). Well integrity can be defined as its capacity to maintain the isolation of fluids in the subsurface reservoirs (Crow et al., 2010). To ensure this isolation, the well casing and the caprock are bonded by a cement sheath; after abandonment, a cement plug is used to avoid upward migration within the casing. However, according to the literature (IEAGHG, 2009; Zhang and Bachu, 2011) wellbore integrity might be compromised by a) operational defects (during the drilling and cementing processes, during the operations where pressure and temperature changes can modify stress conditions, during the abandonment process) or b) chemical changes especially in the context of $CO_2$ storage where different chemical environments can be possibly found.

The evolution of the well integrity is therefore a complex combination of several physical processes (hydrological, thermal, mechanical and chemical at least) on the different materials and elements (formation, cement, casing, interfaces, annuli). The issue addressed in this study is the behaviour of the complete wellbore system in different conditions and especially under influence of $CO_2$. For this purpose, we present, in this paper, a new experiment for following the evolution of the well integrity over time due to changes in well conditions (pressure, temperature and fluids in contact with the well) in the context of $CO_2$ geological storage.

## 2. Design and experimental plan

An in situ experiment has been designed and is being run in the Mont Terri underground rock laboratory (URL), Switzerland, at an intermediate scale between the laboratory experiments (which offer the opportunity to assess specific phenomena over time) and field observations (which allow an assessment of the entire system in subsurface at a specific time). The Mont-Terri is an anticline of the Folded Jura (North-Western Switzerland). The URL galleries intersect the Opalinus Clay formation, an overconsolidated shale (Bossart, 2005).The present overburden over the URL is around 300 m and the maximum one was 1200 m (see Figure 1).

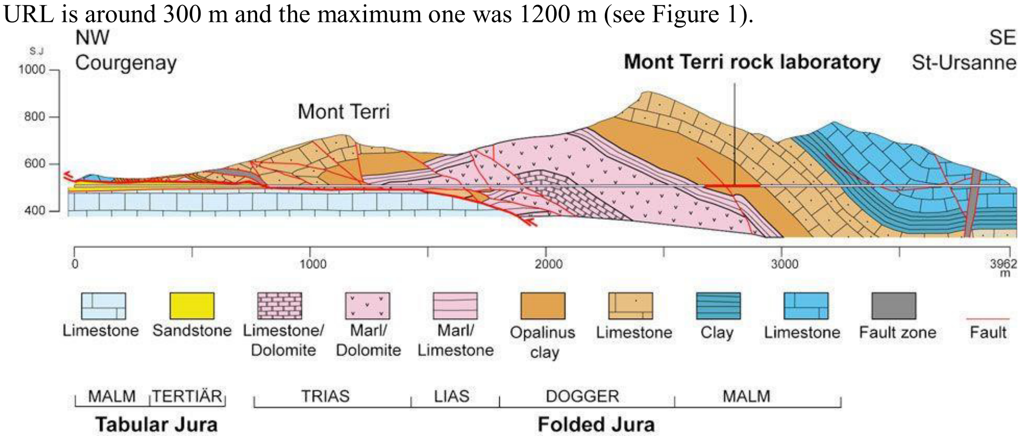


Figure 1: Mont-Terri anticline (after Mont Terri project website, 2013)

The experimental setup has been designed as follows: a small section of a wellbore is reproduced in the Opalinus Clay of the underground rock laboratory (caprock-like formation) at scale 1:1 (5.5 '' casing and Ø198 mm borehole), using carbon steel for the casing and class G cement. As shown on Figure 2, below and above the well section, two different intervals have been designed for a continuous monitoring of the pressure and temperature conditions or for fluid injection and extraction (for fluid sampling for instance).

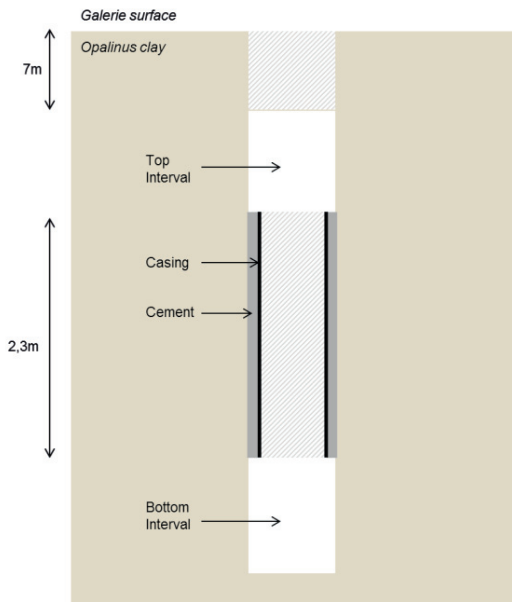


Figure 2: concept of the experimentation with the two observation intervals (not to scale)

The experimental protocol contains several stages:

1- Drilling, relaxation and well completion (achieved end 2012, beginning 2013);
2- Initial state characterization (March 2013);
3- Temperature cycle in the system and characterisation (April 2013 – December 2013);
4- Injection of pore water with dissolved $CO_2$ and tracers, and characterization (2014).

The characterization of the system includes both performing hydro-tests to quantify the hydraulic properties of the well and their evolution over time, and sampling the fluids to analyse the geochemical composition and changes. Hydro tests consist in constant head tests (constant pressure step imposed in the bottom interval, and analysis of the response in the top interval) and in steady state tests (constant head in the bottom interval and constant extraction rate in the top interval, and analysis of the pressure difference between the intervals).

This protocol allows the characterisation of the evolution of the well integrity according to temperature changes, to pressure changes and to changes in the fluid composition (influence of a $CO_2$-rich fluid).

## 3. Results and discussion

The evolution of the well integrity is assessed with the modeling of the hydro-tests results and by the quantification of the effective well permeability (concept presented in Gasda, 2008): the effective well permeability is computed as the equivalent permeability of the cemented sheath that mimics the well hydraulic property, i.e. the equivalent permeability of the cement if the total flow would occur homogeneously in this porous medium. This is therefore an indicator of the hydraulic conductivity of the well due to the numerous potential flowing paths that might exist.

To interpret the data, a 2D-radial numerical model was developed using TOUGH2 code (Pruess et al., 1999). In addition to the effective well permeability that is the main variable of interest, the caprock permeability, the intervals compressibility, and the boundary conditions in terms of pressure appear to be of non-negligible importance. The intervals compressibility has been calculated independently over time, when water was injected in the intervals (during the CH tests for instance). The caprock permeability and pressure boundary conditions are derived from different relaxation tests, which have been performed in the intervals, and are validated by the mass balance between the water injected and water extracted from the system.

### *3.1. Summary of the results*

The characterization of the initial state has been made during one month: a quasi-constant well effective permeability of 20 mD has been retrieved during this period both by two constant head tests (one at the beginning and one at the end of the observation period) and by steady state tests. The increase of the temperature by heating of the lower interval (from the initial 16 °C to 50 °C) has led to a progressive decrease of effective well permeability down to $4\times10^{-2}$ mD (i.e. 3 orders of magnitude decrease). The temperature was then decreased to 30 °C to limit the effects of temperature. During this stage at 30 °C, several pressure increases have been imposed (magnitudes of respectively 3, 4, 8 and 8 bars). All of them show a significant increase in the effective well permeability after the pressure increase (the lowest increase was a 400%) and then a slow return to initial well effective permeability value. The same pressure tests were performed after replacing the bottom interval water with pore water + dissolved $CO_2$: four and five months after, an increase of the well effective permeability of 80% and 20 % was observed respectively for a 8 bar and a 6 bar test.

### *3.2. Discussion*

The results presented above confirm the ability of the chosen design to provide an estimation of the evolution of the well integrity over time.

The estimation of the effective well permeability over time seems to show a significant temperature effect. This temperature effect might be due to the material expansion due to the warming-up or to geochemical reactions that would have been enhanced by the temperature increase: thermal and geochemical modeling were performed and showed that none of these reasons could be excluded. The hydraulic modeling and more particularly the mass balance in both intervals seem to indicate a closing of the permeability in the last tens of centimeters of the well, i.e. principally in the warmer zone of the well.

The evolution of the effective well permeability in accordance with the abrupt changes of pressure that were imposed seems to indicate that the water flow occurs mostly at interfaces rather than through the cement matrix. This assumption is strengthened by the comparison between the observed evolution of the fluid composition in the two intervals before $CO_2$ was injected and the results of the reactive transport modeling: the small evolution of the fluid composition in the top interval cannot match a flow that would have reacted significantly with the cement by passing through the cement matrix. In addition, the quantitative estimation of the flow towards the caprock formation shows that this flow is likely to occur at the outside of the cemented sheath i.e. at the cement/caprock interface.

Interestingly, the effects of the abrupt changes of pressure are significantly lowered after dissolved $CO_2$ was injected in the system. This could be a sign of carbonation occurring at the interfaces that would limit the flow even with high pressure changes. This needs to be confirmed notably with the results in terms of fluid composition changes (fluid composition analysis and geochemical modeling) and with the observation and characterization of mineralogical changes that are planned after the over-coring of the system.

## Acknowledgements

The research leading to these results has been carried out in the framework of the ULTIMATE-$CO_2$ Project, funded by the European Commission's Seventh Framework Program [FP7/2007-2013] under grant agreement n° 281196. The ULTimate$CO_2$ consortium would like to thank Swisstopo and Obayashi for funding a part of this experimentation.

## References

Crow, W., Carey, J.W., Gasda, S., Williams, D.B., Celia, M., Wellbore integrity analysis of a natural $CO_2$ producer. International Journal of Greenhouse Gas Control 2010; 4 (2), 186–197.

IEAGHG, 2009, Long Term Integrity of $CO_2$ Storage – Well Abandonment, 2009/08.

Zhang, M., Bachu S. Review of integrity of existing wells in relation to $CO_2$ geological storage: What do we know? International Journal of Greenhouse Gas Control 2011; 5:826–840

Bossart, 2005, Characteristics of the Opalinus Clay at Mont Terri. Available (30/01/2014) at

http://www.mont-terri.ch/internet/mont-terri/de/home/geology/key_characteristics.parsys.49924.DownloadFile.tmp/characteristicsofopa.pdf
Pruess, K., Oldenburg, C.M., Moridis, G.J.: 1999. TOUGH2 User's Guide, Version 2.0. LBNL Report LBNL-43134.