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

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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. 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 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.

An *in situ* experiment has been designed and is being run in an underground rock laboratory (Mont Terri, 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 purpose is here to follow the evolution of the integrity of the whole well system both for hydrogeological and geochemical aspects. Modelling and lab experiments, including material characterization are performed in parallel to enable a better interpretation and understanding of the observations.

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. 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).

The experimental protocol contains several stages:

1- Drilling, relaxation and well completion;
2- Initial state characterization;
3- Temperature increase in the system and characterisation;
4- Injection of pore water with dissolved CO_2 and tracers, and characterization.

The characterization of the system includes both performing hydro-tests (continuous and constant-head 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. Stages 1, 2 and 3 are now completed and stage 4 is in progress. The first results (of stage 2 and 3) confirm the ability of the chosen design to assess well integrity over time. It also shows first trends in the evolution of integrity especially under influence of the temperature: the equivalent permeability of the wellbore decreased significantly during that stage, improving the well integrity.

Three modelling methods are used to predict the results of the experiment or to use the recorded data: 1) flow and transport modelling, 2) geochemical modelling, and 3) reactive transport modelling (TOUGH2 used for 1, and PhreeqC and TOUGHREACT for 2 and 3). Flow modelling has been associated with the hydraulic tests in order to quantify the well integrity in terms of equivalent permeability during stage 2 and 3. Temperature effects have been included in the models to understand the changes that occurred in terms of effective permeability during stage 3. Geochemical models have been developed to evaluate the validity of chemical sealing as a potential explanation for the increase of well integrity observed during stage 3. The models are also used as predictive tools on the potential evolutionary scenarios for stage 4, regarding water chemistry variations and mineralogical changes. They have been notably useful to calibrate the conditions of the dissolved CO_2 in terms of tracers used, and of sampling and in-line fluid analysis protocol. Each of those models will be progressively refined during the CO_2-dissolved injection (stage 4) with the aim of aiding the interpretation of the observed processes and phenomena.

Finally this field experiment-modelling integrated framework is completed by laboratory characterizations and experiments (in autoclave principally) carried out to provide input data for the modelling with regards to cement, caprock and their reactivity with pore water and CO_2.