CATO-2 Deliverable WP3.4-D04
Progress report: Development of numerical models of (coupled) processes

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1 Executive Summary (restricted)

Deliverable D04 describes progress on development of numerical models of (coupled) mechanical and chemical processes relevant for wellbore integrity. The activities related to the D04 are planned to be executed from year 2 to 5 of the CATO-2 project. In agreement with the project plan no activities were executed during the first year of the project. In this progress report we provide description of our plans with respect to the planned activities for years 2 to 5 of the project.

We present an analysis of the processes that can affect well system. Processes that can lead to the mechanical damage of cement sheath in the axial direction are of particular importance as they can cause creation of communication pathways for migration of CO_2 upwards across the top seal. Axial deformation affects practically every well because each reservoir compacts and extends to some extent during production and injection. Axial well deformation and its effects on axial fluid migration were barely studied before. This is in contrary with radial and shear deformation, which were widely studied and reported in the literature.

The conceptual model of axial well deformation will be utilised to develop generic geomechanical numerical models of a reservoir with a production/injection well. The well system will be explicitly represented with the steel casing, cement sheath and the surrounding damaged rock. Geomechanical models will be used to investigate further the effects of reservoir compaction and decompaction on possible deformation along cement-casing and cement-rock interfaces and possible implications for fluid flow.

Distribution List

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Document Change Record

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Version	Nr of pages	Short description of change	Pages
2010.08.31		Final deliverable	

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2 Applicable/Reference documents and Abbreviations

2.1 Applicable Documents

(Applicable Documents, including their version, are documents that are the “legal” basis to the work performed)

	Title	Doc nr	Version date
AD-01	Beschikking (Subsidieverlening CATO-2 programma verplichtingnummer 1-6843	ET/ED/90780 40	2009.07.09
AD-02	Consortium Agreement	CATO-2-CA	2009.09.07
AD-03	Program Plan	CATO2-WPD-3.04-D.04	2009.09.29

2.2 Reference Documents

(Reference Documents are referred to in the document)

	Title	Doc nr	Version/issue	Date

2.3 Abbreviations

(this refers to abbreviations used in this document)

3 General Text

3.1 Introduction

This report represents the first year progress report on "*Development of numerical models of (coupled) processes"* (deliverable D04), which is a part of the WP-3.4 *"Well Integrity"* of the CATO-2 project. The reporting period is from project start 2009.04.15 until 2010.08.31.

The report addresses the task T3.4.2 *"Chemical and mechanical degradation: interaction of processes and materials".* The objectives of this task are related to evaluation of the chemical and mechanical degradation potential of the wellbore system through experimental testing and numerical modelling of coupled processes. The present report deals in particular with the second objective related to gaining insight into the interaction between chemical and mechanical processes relevant for wellbore integrity by numerical modelling. The aim is to develop numerical models describing the effects of chemical degradation of well materials and of associated coupled processes (mechanics, chemistry, thermal, multi-phase flow) on the wellbore system scale, to improve the quantitative understanding of wellbore system behaviour; to perform validation against experimental results, field and monitoring data. The partners contributing to task T3.4.2 are TNO B&O and UU.

The activities related to deliverable D04 are planned to be executed from year 2 to 5 of the CATO-2 project. In agreement with the project plan no activities were executed during the first year of the project. In this progress report we provide extended description of our plans with respect to the planned activities for years 2 to 5 of the project, backed up with the relevant literature.

3.2 Background

Wells represent potential pathways for escape of injected CO_2 from the storage complex and therefore a significant risk factor for the containment. In the context of geological storage of CO_2, well integrity has to be ensured over much longer time scales (100's to 1000's of years) than in the case of hydrocarbon production (10's of years). Ensuring well integrity not only during injection period but also in the post-operational period over such long timescales represents a new challenge for the CCS projects not encountered before in the O&G industry. The long term-ability of wells to retain CO_2 has been identified as a significant potential risk for the long-term security of geological storage facilities (WBI, 2005, 2006, 2007).

The risk of leakage through "old" abandoned wells requires particular attention. These wells were completed and abandoned under different standards and practices which were in general less comprehensive than those commonly used at present. In addition, old wells were not completed and abandoned taking into account future use of abandoned reservoirs for CO_2 storage. The risk of leakage through abandoned wells may be a showstopper for a CCS project as it was in the case of CO_2 storage in the depleted De Lier field (Hofstee et al., 2008). The project was discontinued during feasibility phase because of a high potential for leakage through old wells that were uneconomic to repair and in some cases practically inaccessible.

Well leakage may occur:

- within the casing, or
- outside the casing.

Leakage within the casing falls beyond the scope of this study because such a leakage can be readily detected in an accessible (non-abandoned) well and successfully mitigated by well engineering techniques available nowadays.
Leakage outside the casing is the primary focus of our study. This leakage is generally difficult to detect, quantify and mitigate.

Well leakage beyond the casing may occur through:

- Cement
- Microannulus, which is a small gap between the casing and the surrounding cement sheath or the sheath and host rock
- The damaged part of the host rock surrounding the cement sheath and casing.

3.3 Processes affecting well system

Diffusion and fracture dominated flow
Intact cement material, used in cement sheaths beyond the casing and in cement plugs within the casing, is generally prone to chemical reactions with CO_2 in the presence of water. Portland-based cements in particular are sensitive to chemical degradation when brought into contact with CO_2-rich water. However, chemical degradation of cement based on a diffusion process only is a very slow process. Degradation rates obtained from the experiments showed that the thickness of alteration front evolves with a square root of time (Barlet-Gouédard *et al.*, 2006).
Based on established empirical relationships, wet supercritical CO_2 will advance ~2.54 cm (=1 inch) through cement in 1 year, while CO_2-saturated water fluid will advance 3.8 cm (=1.5 inch) in 1 year. However, 170,000 and 240,000 years will be required for a migration length of 10 m, respectively. Portland cement class G was used in the experiments (prepared with fresh water, water/cement ratio =0.44, cured for 72 hours at 206.8 bar and 90 ℃). The samples were exposed for up to 3 months to wet supercritical CO_2 and CO_2-saturated water at 280 bar and 90 ℃.
Degradation starts with the process of carbonation which produces carbonates and amorphous silica gel, followed by the process of leaching which dissolves carbonates so that only the amorphous silica gel remains. The leached cement has an increased porosity and permeability with regard to non-degraded cement, and an extremely low strength.

Well cement in field conditions is different from intact cement material. Well cement in sheath may not be continuous over a cemented well interval; it may contain voids, embedded mud, fluids and viscous geomaterials such as squeezing salts. Well cement may be fractured due to shrinkage during cement setting or as a result of mechanical and thermal loading during well completion and operation. Absence of cement and presence of fractures and other migration pathways can significantly accelerate cement degradation by diffusion in field conditions. On the other hand, if CO_2 is migrating slowly upwards it loses much of its corroding power which could lead to precipitation of carbonate and healing of leakage pathways.

Mechanical processes
Well history and future well use have to be taken into account when evaluating the risk of leakage through a well. The life of a well comprises the phase of drilling, completion, production/injection, abandonment and post-abandonment. In each of these phases the well system is exposed to different mechanical and pressure loads, and possibly thermal loads. Mechanical loading occurs due to stress redistribution in the rock surrounding a well, change in reservoir pressure and

internal well pressure as well as due to temperature change resulting from, for example, injection of cold fluid (CO_2) into hot reservoir. Mechanical processes represent the driving force that can initiate creation of preferential pathways for CO_2 escape from the containment along a well. Other processes, such as geochemical, may enhance the permeability of damaged zones accelerating leakage.

The mechanical impact of production and subsequent CO_2 injection causes radial, axial and shear deformations which all may jeopardize the integrity of a well.

Radial deformation of cement sheath is commonly caused by shrinkage during cement hydration and an increase in the pressure/temperature inside the casing during the operational life of the well. As a result, cracking of cement sheath or debonding at rock/cement or cement/casing interface can occur allowing for radial and vertical migration of fluids. Next to internal loading, the casing can also be exposed to large radial external pressures due to creep or viscous movement of the surrounding rock, typically rocksalt. Imperfect hole quality greatly impacts the induced loads on the well casing and causes yielding of the casing for stress and temperature conditions expected in some field settings (e.g., in the Gulf of Mexico; Willson et al., 2003). For a perfectly circular uncemented casing, or a cemented casing, loading over the well is uniform and not sufficient to induce casing yield.

Axial deformation of wells occurs during reservoir production, when the reservoir compacts, and during the CO_2 injection phase, when the reservoir undergoes extension (Figure 1). Due to a huge strain incompatibility at the cement-casing interface (steel casing is about 50 times stiffer than the cement and the surrounding rock), this bond will most likely fail leading to the creation of microannulus, which represents a possible leakage pathway for CO_2 escape.

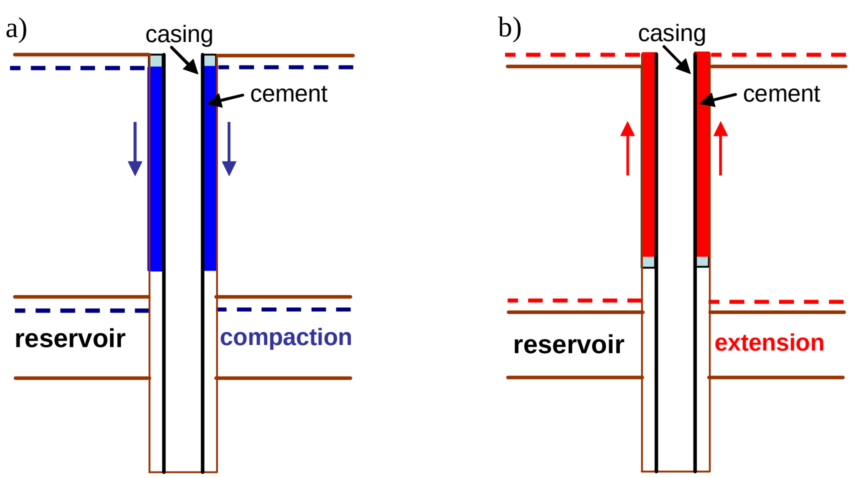

Figure 1 a) Compaction and b) decompaction (extension) of the reservoir leading to debonding at cement/casing interface.

Shear deformation of wells occurs due to triggering of discontinuities or faults within or outside the reservoir during production or injection. Well casing can be deformed and sheared; cement sheath, if present in the shear zone, can be fractured. Shear localisation zones are typically located in the over- and underburden close to the edges of a reservoir. They also often develop along interfaces between geomaterials of different stiffness, e.g., along contacts between different lithologies. Estimation of the magnitudes of stress changes and accompanying deformations during the production and the CO_2 injection can be done by using analytical tools, for a preliminary assessment, and numerical tools, for a detailed analysis.

3.4 Proposed modelling of (coupled) processes

Processes that can lead to the mechanical damage of cement sheath in the axial direction are of particular importance as they can lead to creation of communication pathways for migration of CO_2 upwards across the top seal. Axial deformation affects practically each well because each reservoir compacts and extends to some extent during production and injection. Axial well deformation and its effects on axial fluid migration was hardly studied before. This is in contrary with radial and shear deformation, which were widely studied and reported in the literature.

The conceptual model of axial well deformation shown in Figure 1 will be utilised to develop generic geomechanical numerical models of a reservoir with a production/injection well. The geomechanical models developed will be used to investigate the effects of reservoir compaction and decompaction on possible deformation along cement-casing and cement-rock interfaces. In numerical models the well will be explicitly represented with the steel casing, cement sheath and the surrounding damaged rock. The models will be three-dimensional (3D), either axial-symmetric or one-quarter of a full 3D model.

A fluid flow model with the same geometry as the geomechanical model will be developed to investigate the effects of possible debonding along interfaces, resulting in permeability enhancement, on fluid flow through newly formed microannuli.

Change in transport and mechanical properties due to geochemical reactions between the well system and injected CO_2 will be taken into account when these effects have been quantified by the experiments planned to be executed within WP-3.4. Geochemical processes usually act over large time scales, which imply that significant changes in material properties of well components may occur late in the life of a well – in the post-abandonment phase of a storage site.

3.5 References

Papers

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