TOUGH2 SIMULATION OF CO_2 LEAKAGE FROM A GEOLOGIC RESERVOIR THROUGH MIXED SANDSTONE/SILTSONE CAPROCK FORMATION

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ABSTRACT

Carbon capture and geological storage has been shown to be a viable solution for long-term disposal of CO_2, to avoid increasing greenhouse gas emissions to the atmosphere. For effective and safe storage, a suitable caprock formation is necessary, with sufficiently low permeability to avoid the upward migration of injected carbon dioxide. Here, we report the results of our TOUGH2 numerical simulation of CO_2 and water flow through a caprock formation within the Rio Bonito Formation, in the Charqueadas Coal Field (south of Brazil). At the injection site, the caprock consists of sandstone (5 m) in the base, followed by a siltstone layer (25 m). The sandstone and siltsone have vertical permeabilities of 1.2×10^{-13} and 2.4×10^{-16} D, respectively. The model was built with a radial grid (1 km radius) with 20 horizontal × 30 vertical cells. Initial temperature and pressure of the formation were set to 30°C and 1.2×10^{7} Pa, respectively. We conducted simulations while varying injection rates (from 1 to 10 kg/s), over a period of 30 days. Preliminary results show that the CO_2 plume reaches the siltstone layer before the injection stops, even at the lower rate. Migration is then reduced by the siltstone, with very low saturation in the first 5 m after one year of simulation.

INTRODUCTION

Increasing fossil fuel consumption by mankind since the Industrial Revolution is causing significant changes in greenhouse gas (GHG) concentrations in the atmosphere, especially CO_2, which may reach levels up to 790 ppm by the end of the 21st century. This will intensify the greenhouse effect, which may significantly raise the Earth's average temperature, enough to cause severe and irreversible climatic change (IPCC, 2007).

Geological storage of CO_2 is among several alternatives and solutions that have been proposed to reduce and stabilize greenhouse gas emissions (Ketzer, 2011).

Carbon capture and geological storage

CO_2 capture and geological storage (CCGS, or simply CCS) is the integrated process in which carbon dioxide is captured and separated at stationary sources, transported to an adequate storage site, and injected into the porous space of deep underground rock formations, such as saline aquifers, oil fields, and coal seams.

CO_2 stored under typical geological conditions is likely to occur in a gas or supercritical phase, with density lower than that of water (~600–800 kg/m^3); thus it will tend to move upward in the reservoir and into the overburden sequence until it seeps to the surface. To ensure that the CO_2 will be retained after the first few years of injection, we must seal the reservoir with an overlying impermeable caprock (permeability typically <0.1 mD).

While being mostly immiscible in water and oil phases, a fraction of the CO_2 will gradually dissolve in the formation water, forming carbonate and lowering the pH of the aqueous phase. This may trigger chemical changes in the rock matrix that can either improve injectivity around the well, or damage the reservoir and/or caprock by affecting the porosity and permeability of the medium. Eventually, dissolved CO_2 may form mineral carbonates, trapping CO_2 permanently in a solid phase in the reservoir; however, this process is likely to proceed very slowly, over thousands of years after injection (Iglesias, Bressan et al., 2009).

These trapping mechanisms of CO_2 in the reservoir are interdependent and may change significantly over space and time, on a geological scale. This is why numerical simulation is a powerful tool, one that is systematically employed, in studies of CO_2 geological storage—helping investigators understand the partition among the trapping mechanisms, predicting the displacement of the free CO_2 phase in the reservoir, and detecting chemical alterations in the rock matrix. The TOUGH2 family of codes is a valuable tool for this application because it is capable of simulating multiphase flow and multi-component transport within porous media, in up to three dimensions (Pruess, 1999).

OBJECTIVES

This work aims to study the containment capacity of a moderately porous siltstone and sandstone caprock overlying a coal seam in the Charqueadas Coalfield, southern Brazil, using a numerical model. Both caprock layers belong to the Rio Bonito Formation, from the Parana sedimentary Basin. The study involves simulating CO_2 migration through the caprock, using TOUGH2 and the ECO2N module (Pruess, 2005).

MATERIALS AND METHODS

This study models the flow of CO_2 injected into an interval of the Rio Bonito Formation, a stratigraphic unit belonging to the Parana Basin. At the point of injection, in the Charqueadas coalfield (state of Rio Grande do Sul, southern Brazil) the formation contains a coal seam of ~10 m in thickness, with intercalating sandstone layers, and is overlain by several meters of mixed sandstone/siltstone layers.

For the simulation, we constructed a non-reactive isothermal flow and transport model using TOUGH2 and the ECO2N module, with water and CO_2 as the mobile phases. The PetraSim graphical interface from Thunderhead Eng. was used to facilitate the model grid construction and input of parameters.

Model

A radial model of 1 km diameter and 30 m height was defined (20×30 cells), where the lower 5 m constituted of sandstone and the top 25 m of a porous siltstone. A 1:1 size-increasing factor was applied in the radial direction for increased refinement near the injection point. Pressure and temperature of the reservoir were set at 120 bar and 30°C, respectively. Figure 1 below presents a simplified scheme of the model.

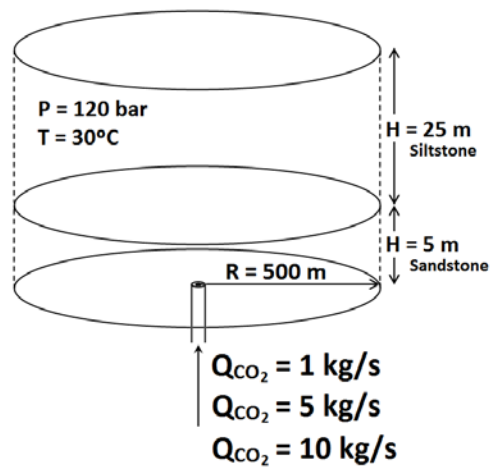

Figure 1. Model scheme

Table 1 below presents the rock properties that were introduced in the model.

Table 1. Rock properties

Property	Siltstone	Sandstone
Density	2520 $kg.m^{-3}$	2650 $kg.m^{-3}$
Porosity	0,158	0,280
Permeabilty	$2,4x10^{-16}$ m^2	$1,2x10^{-13}$ m^2

As a variable for analysis, three different CO_2 leakage rates were tested for comparison: 1 kg/s, 5 kg/s, and 10 kg/s. CO_2 enters the model at a single point through the lower central part of the grid, for a period of 30 days, which is the time of injection at the site.

Table 2. Summary of variables of simulation

Simulation	Time	CO_2 injection rate
S1	30 days	1 $kg.s^{-1}$
S2		5 $kg.s^{-1}$
S3		10 $kg.s^{-1}$

RESULTS

The main objective of this work was to verify the containment capability of the porous sandstone/siltstone layers with respect to the upward migration of the CO_2 plume after permeation through the coal seam. Figure 2 shows the CO_2 gas saturation after 30 days (end of injection) with the different injection rates. The figure shows that the plume migrates rapidly through the sandstone layer, reaching the bottom of the siltstone in all cases. For the higher injection rates (Figures 2b and 2c), the plume starts to spread below the siltstone layer (because the permeability is lower), containing the migration. This confinement is not very effective, however, because the siltstone is moderately porous and permeable. For high injection rates (Figure 2c), the central, lower part of the siltstone layer has a significant gas saturation after 30 days of simulation.

The same trend in the results is observed for the solubilized CO_2 fraction (Figure 3a-c). The plume spreads in the sandstone ~100 m horizontally from the center. (Note that the figures are not to-scale.)

Figure 4 shows the resulting CO_2 saturation one year after the beginning of injection (which lasted 30 days). As expected, the horizontal spread is more pronounced, reaching ~200 m from the center. However, a rather significant amount of CO_2 still penetrates ~5 m into the siltstone layer.

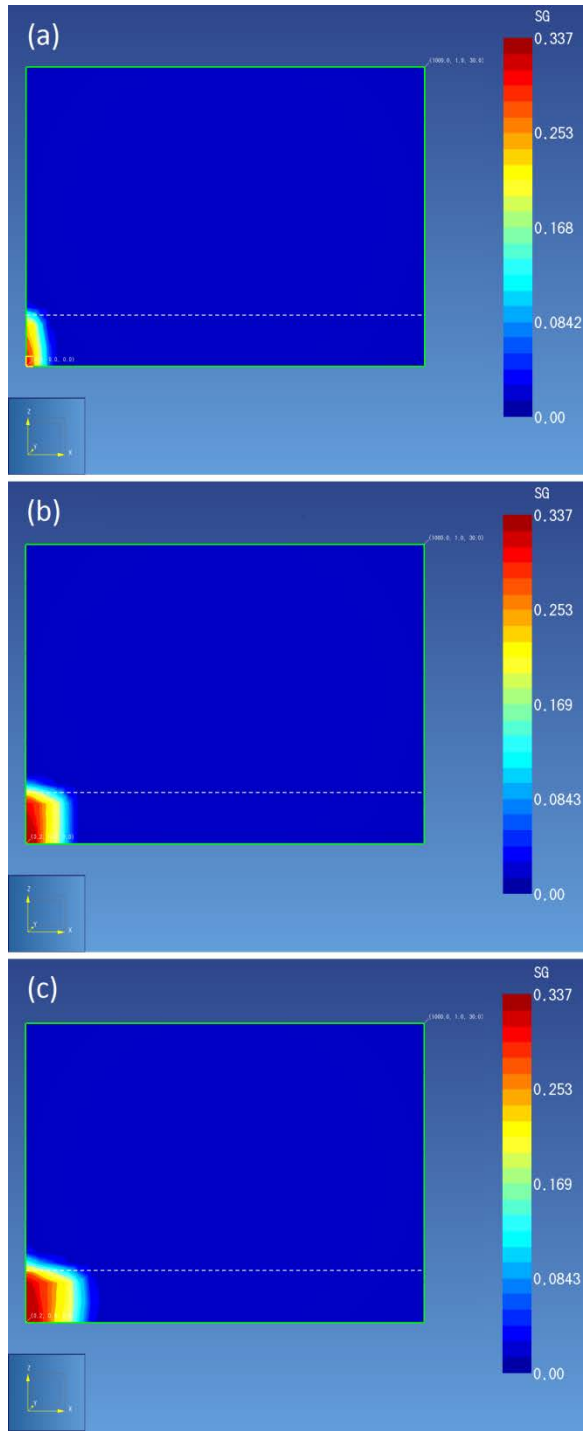

Figure 2. CO_2 saturation at (a) 1 $kg.s^{-1}$, (b) 5 $kg.s^{-1}$ and (c) 10 $kg.s^{-1}$ injection rates after 30 days (Not to scale. Dashed line shows separation between sandstone and siltsone.)

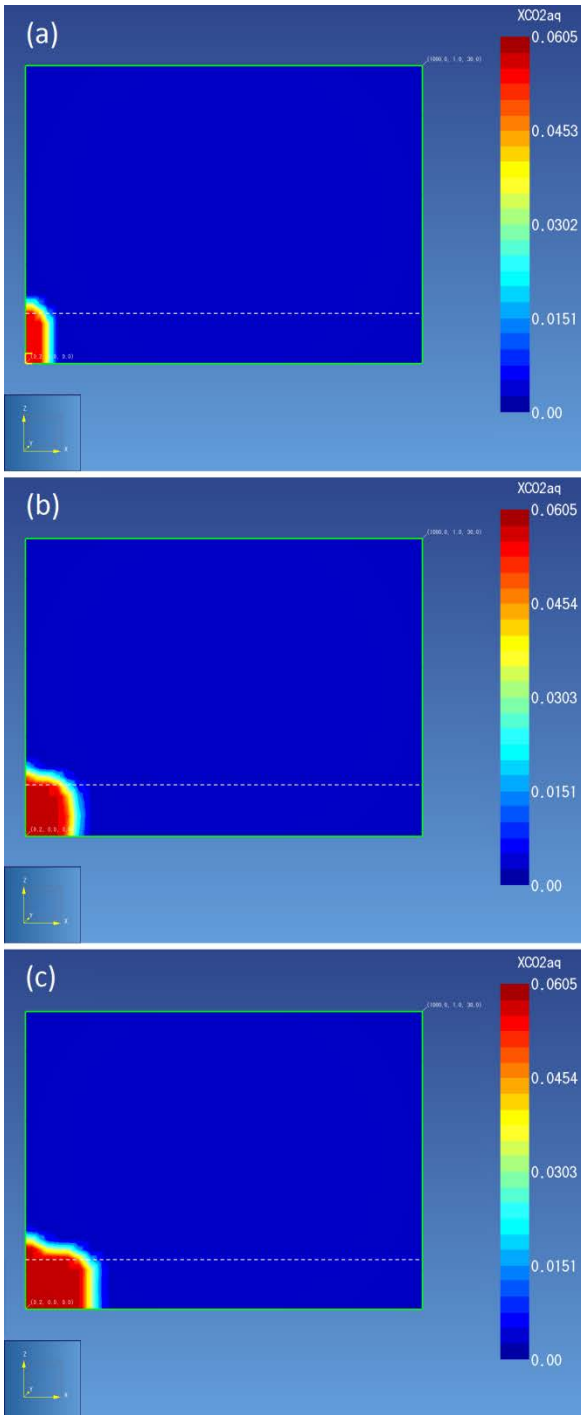

Figure 3. Aqueous CO_2 molar fraction at (a) 1 kg.s^{-1}, (b) 5 kg.s^{-1} and (c) 10 kg.s^{-1} injection rates after 30 days (Not to scale. Dashed line shows separation between sandstone and siltsone.)

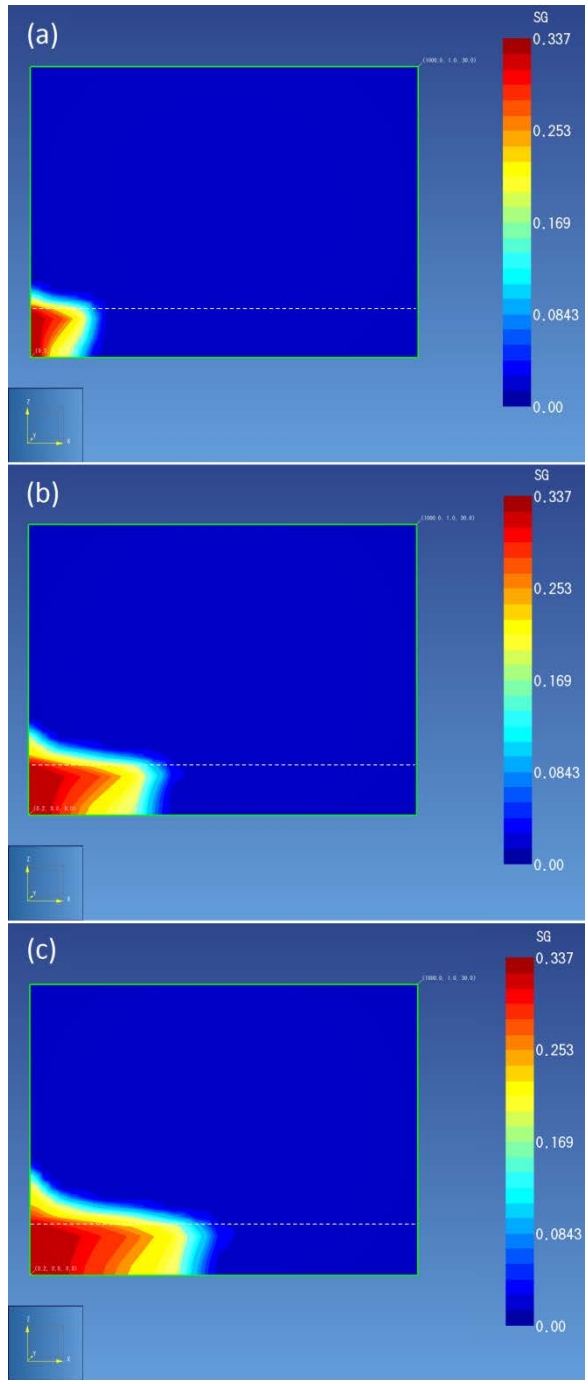

Figure 4. CO_2 saturation at (a) 1 kg.s^{-1}, (b) 5 kg.s^{-1} and (c) 10 kg.s^{-1} injection rates after 1 year (injection stops at 30 days). (Not to scale. Dashed line shows separation between sandstone and siltsone.)

CONCLUSIONS

Using numerical simulations of non-reactive flow of CO_2 and water in a geological system composed of sandstone with a siltstone caprock, we analyzed the performance of that system in terms of its ability to contain the upward flow of a CO_2 plume. As expected, given its low porosity and permeability, the sandstone layer is unable to contain the flow: it allows the plume to reach its top during the injection period. The siltstone layer, being less permeable, is able to partially contain this flow, causing the plume to spread through the sandstone layer. However, the siltstone is still sufficiently permeable, allowing a steady migration of CO_2 through this layer and indicating the incomplete containment characteristics of such an overburden.

Further studies, including reactive transport (using TOUGHREACT) are being carried out, as well as different model constructs (finer grids, longer simulation times), which will allow a better comprehension of this caprock capacity for containment of injected CO_2.

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