Modeling of single-well CO_2 injection-withdrawal experiment to be carried out at the Heletz site

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Abstract

Single-well injection-withdrawal (push-pull) test with alternating injections of water, CO_2 and C O_2 saturated water and withdrawal of formation fluid at selected stages of the experiment, will be part of the experimental test suite at the Heletz site, Israel, the main CO_2 injection site of the EU FP7 MUSTANG project. A single-well push-pull experiment is an attractive alternative and support to two-well injection-monitoring tests as uncertainties due to CO_2 transport and associated parameters in the heterogeneous media between the wells are greatly eliminated in the interpretation of this test. Taking this approach Zhang et al. (2011) presented a test sequence for determining the residual phase trapping using thermal, hydraulic and noble gases tracer tests. A similar basic approach is implemented in this study The present study presents the results of model simulations with the TOUGH2/ECO2N model aiming to aid the design of the experiment to be carried out at Heletz and to find an optimal test sequence, based on the data presently available. The site has previously been extensively explored for oil exploration purposes - but the injection will take place in the saline part of the formation - and is therefore relatively well understood. The target layer where the injection will take place is sandstone layer at the depth of 1600 m. Model simulations are carried out to simulate different alternative injection/withdrawal scenarios, to test the incorporation of heating as part of the test sequence and to carry out sensitivity studies concerning parameters where uncertainties exist. Simulations with different assumed residual gas saturations, heater effects and amount of injected CO_2 are carried out. The results are interpreted in terms of how the properties of interest in the target layer, in particular the residual CO_2 gas saturation, is seen in the monitored, measurable response quantities of temperature, pressure and mass fraction of CO_2 in the aqueous phase and how this observability is changing with different test conditions and in-situ properties. The results show that a reduction in pressure could be seen between the hydraulic test responses at the different CO_2 saturation conditions and that the temperature response depend on in-situ CO_2 gas saturations as well as the heating effect (20, 30 and 50 W/m), where the choice of effect is crucial to be able to observe a response. Simulation results also
indicate that the amount of injected CO_2 impacts the distribution between the phases.
Future studies will include (i) a more detailed description of the system as more in-situ data from the particular well becomes available, (ii) more comprehensive modeling approach, including e.g. the effect of hysteresis and (iii) finally also incorporation of specific tracers into the modeling scenario.

Reference:
Zhang Y., Freifeld B., Finsterle S., Leahy M., Ennis-King J., Paterson L., Dance T. Single-well Experimental Design for Studying Residual Trapping of Supercritical Carbon Dioxide. Journal of Greenhouse Gas Control 5 (2011) 88-98.

1. Background & aim of study

This study concerns pre-experimental modeling of a one well push-pull test with CO2 at the main injection site of the large-scale EU FP7 project MUSTANG. Aims:

•Create a model of the site to facilitate computational pretesting of the experimental design of the one well push-pull CO2 injection test.

•Relate parameters of interest to measurable quantities. Preliminary simulations to investigate the feasibility of hydraulic and thermal methods and pumping scheme to determine residual CO_2 saturation and in-situ solubility/dissolution.

2. The model

•For the study the TOUGH2/ECO2N numerical simulator (Pruess, 2005) was used.

•A radially symmetric model with a depth of 5.8 m and a radius of 500 m was created. The total number of grid blocks was 2407 (29x83).

•The model was homogeneous with parameters based on average formation properties.

•Residual water and gas saturation were assumed to be 0.3 and 0.09, respectively.

•Formation heat conductivity under fully liquid-saturated and desaturated conditions were chosen as 4.01 and 2.54 W/m°C, respectively.

Formation properties

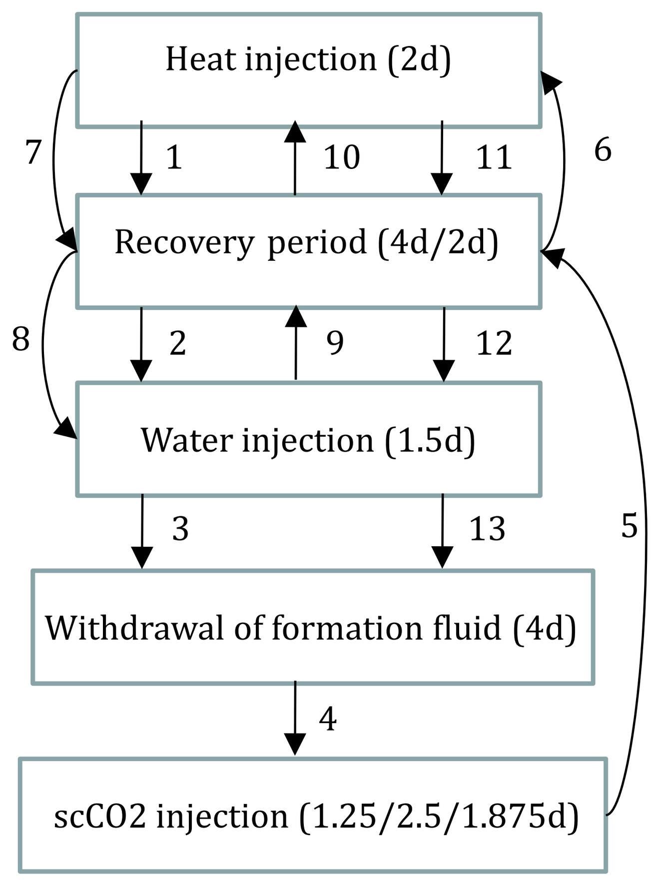
Thickness of sandstone layer [m]	5.8
Bottom depth [m]	1632.8
Pressure [Pa]	1.47E+07
Average porosity [%]	17.2
Average permeability [md]	78
NaCl mass fraction [-]	0.04988
Temperature [°C]	67

3. Investigated scenarios

•Push-pull experiment with heating, injection of water or/and CO_2 and withdrawal of formation fluids. Sequence in accordance with Zhang et al. (2011). Monitoring of temperature, pressure and mass fraction of CO_2 in the aqueous phase in the well.

•Different heating scenarios (20, 30 and 50 W/m heating) and residual gas saturations.

•Different scCO_2 injection volumes impact on e.g. in-situ solubility. Injection of 100, 150 and 200 tons during 30, 45 and 60 h respectively.



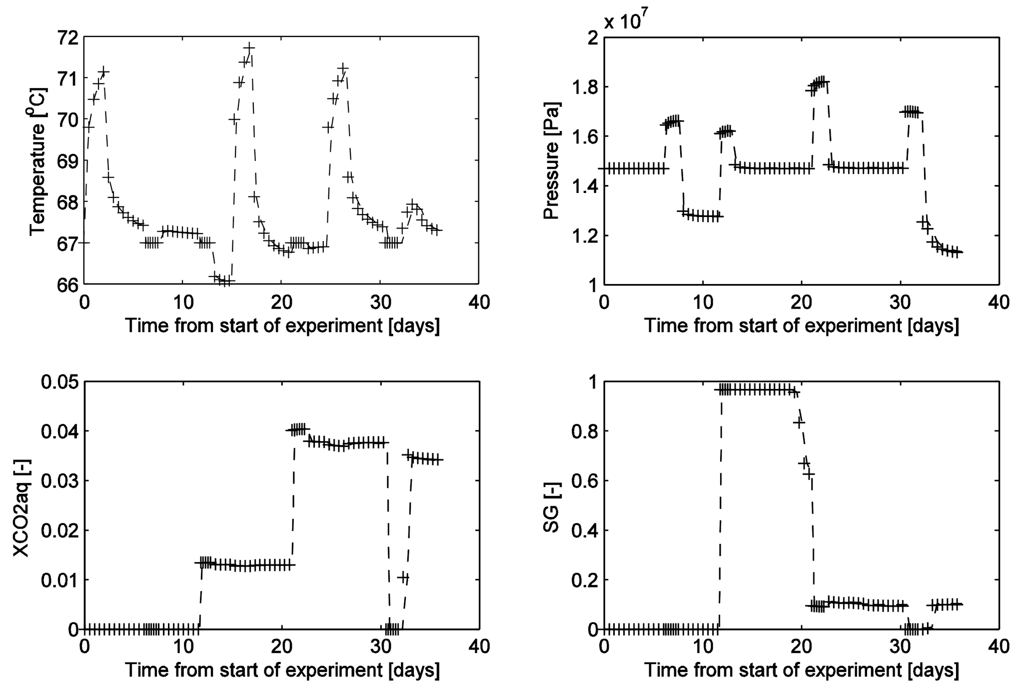
Simulation steps

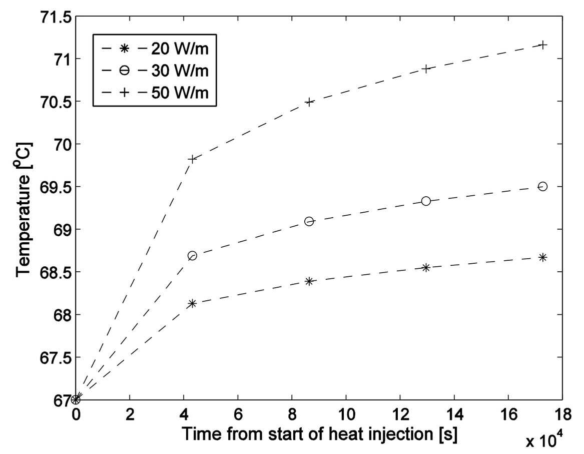
4. Results

•Results from the push-pull simulation. Monitoring of temperature, pressure and mass fraction of CO_2 in the aqueous phase in the well.

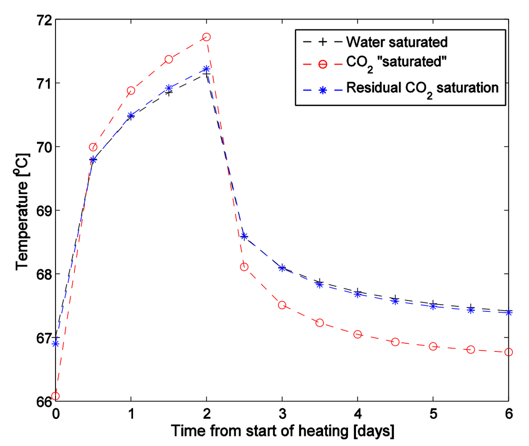
•Results from the 20, 30 and 50 W/m heating scenarios.

•Results from the simulations with different residual gas saturation. An impact of the residual gas saturation on the temperature response during heating could be seen. Also a reduction in pressure of 1.458 and 6.0302 MPa between the first and second withdrawal could be seen for residual gas saturations of 0.09 and 0.19 respectively.





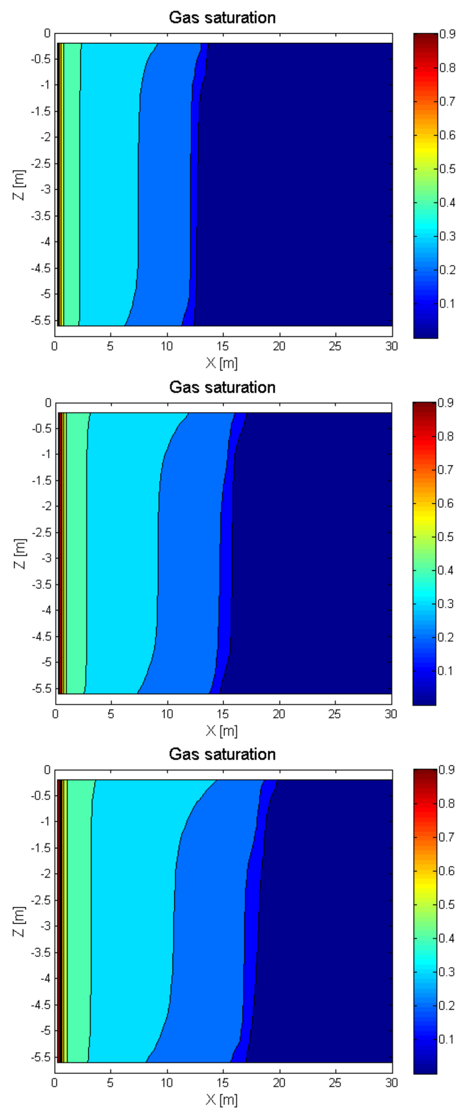
The impact of heater effect on temperature in the bottom well element.



The temperature response of heating at different saturations.

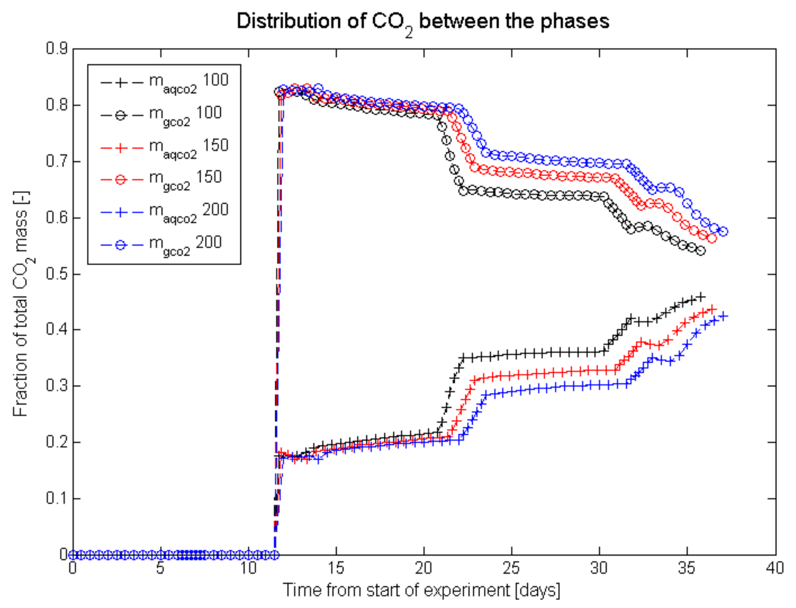
Temperature increase during heating for different residual gas saturations

	0.09	0.19	0.29
dT (water saturated)	4.14	4.14	4.14
dT (after CO2 injection)	5.64	5.78	5.78
dT (residual CO2 saturation)	4.32	4.51	4.94



scCO_2 saturation at the end of scCO_2 injection. The 100, 150 and 200 tons scenario.

Simulations of different mass injection of scCO_2 (100, 150 and 200 tons, during 30, 45 and 60 h respectively) showed only minor effects on the thermal and pressure responses. This had however an effect on areal plume extent and on distribution between the phases (solubility).



Impact of injected CO_2 mass on distribution between the phases (solubility).

5. Conclusions

•A radially symmetric model was created to evaluate the push-pull experiment. The simulation results are of a preliminary nature.

•Thermal methods could potentially be of interest when determining the residual saturations as different residual gas saturations in these simulations resulted in different temperature responses. Combined with laboratory measurements this could be used when determining parameters.

•The amount of injected CO_2 impacts the distribution between the phases however further simulation studies with tracers could potentially contribute to quantification of in-situ solubility.

•Future studies will incorporate tracers, hysteresis and reactive transport into the modeling scenario.

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