Numerical Simulation: Field Scale Fluid Injection to a Porous Layer in Relevance to CO_2 Geological Storage

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Abstract

1. Introduction

CO_2 geological storage can help to provide a "bridge" from a fossil-fuel dependent system to a more diversified energy portfolio (Socolow and Pacala, 2006). A monitoring project was conducted at a large scale commercial CO_2 injection at Cranfield Field, Mississippi, in which pressure monitoring for an above-zone monitoring interval (AZMI) has been attempted for the first time in relevance to CO_2 injection projects (Hovorka et al., 2013). The CO_2 injection zone and AZMI is hydraulically separated by very low permeability layers that stack up to 120m in thickness. Pressure measurements revealed increase in the pore pressure in the AZMI with trends linked to increase in pressure measured in the reservoir. In this study, we simulate the geomechanical response of pressure in the AZMI to injection process and thus interpret the measurement data.

2. Use of COMSOL Multiphysics®

We used COMSOL Multiphysics® to simulate the fluid injection into a porous injection zone underground. In the Subsurface Flow Module, the Poroelasticity interface combines a transient formulation of Darcy's law with the Solid Mechanics interface. We built the simulation model as simple as possible without losing geometric relevance to the injection site (Figure 1). All necessary initial and boundary conditions for Darcy's law and solid mechanics were set in accordance with the field conditions. Fluid injection rate, which was imposed on the left-end of the injection zone, is initially 175kg/min (0.1MtCO_2/yr) and doubles after 19days, and increases again to 500kg/min (0.3MtCO_2/yr) after 183 days. Total simulation time is about 230 days (≈107.3seconds).

3. Results

We obtained result such as the bottom-hole pressure near the injection well and in AZMI, displacement, and pore pressure-stress coupling. Evolution of bottom-hole pressure correlated well with the injection rate (Figure 2-a), and the final increment, ΔP~14MPa, is comparable to the field data (ΔP~10MPa). We also compared changes in pore-pressure at the specific location in AZMI with the actual field data (Figure 2-b). Field data and numerical simulation results shows good agreement: both show a jump right after CO_2 injection started and exhibit another jump following increase in the injection rate. Final increment in the pore-pressure is also comparable (ΔP~40kPa).

We were also able to investigate displacements at the surface: maximum value reached ~1.2mm at the central point after 230days (Figure 3-a). Finally, coupling of pore pressure-stress was observed during the numerical simulations (Figure 3-b). The observed ratio of increase in total radial stress to increase in pore-pressure is similar to a theoretical value ΔSrr/ΔP≈0.82. Interesting observation is vertical stress is also coupled with the pore pressure (ΔSzz/ΔP≈0.3).

4. Conclusions

Numerical simulation for fluid injection into a porous interval using COMSOL helped to interpret the field data: increase in the pore pressure resulted from poromechanical effects, not from fluid leakage. Besides, we obtained additional information such as displacements and pore pressure/stress coupling. In the future, this numerical simulation method can be utilized in various ways: 1) preliminary evaluation of geomechanical responses, 2) more reliable risk assessment of geomechanical failures, and 3) interpretation of field monitoring data.

Reference

Hovorka, S.D. et al., 2013. Monitoring a Large-Volume Injection at Cranfield, Mississippi —Project Design and Recommendations. International Journal of Greenhouse Gas Control, http://dx.doi.org/10.1016/j.ijggc.2013.1003.1021.

Rutqvist, J., 2012. The Geomechanics of CO2 Storage in Deep Sedimentary Formations. Geotechnical and Geological Engineering 30, 525-551.

Socolow, R.H., Pacala, S.W., 2006. A Plan to Keep Carbon in Check. Scientific American 295, 50-57.

Figures used in the abstract

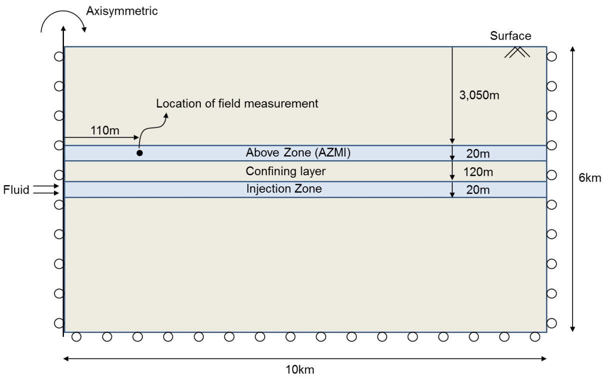

Figure 1: Simulation model and geometric conditions in COMSOL.

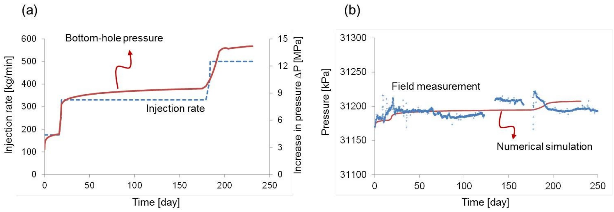

Figure 2: Highlights of numerical simulation results. (a) Imposed injection rate (dotted line) and resulting bottom-hole pressure near the injection well (solid line) and (b) comparison of bottom-hole pressure between field measurement data (dots) and numerical simulation results (solid line).

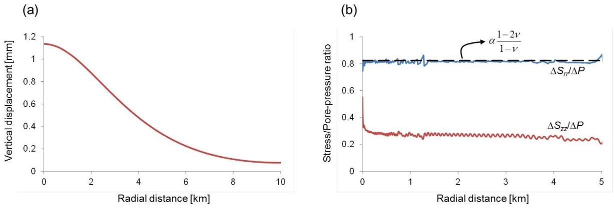

Figure 3: Additional observations from numerical simulation. (a) Calculated vertical displacement at the surface after 230days elapsed and (b) pore-pressure/stress coupling: ratio of change in radial stress to pore-pressure ΔSrr/ΔP and ratio of change in vertical stress to pore-pressure ΔSzz/ΔP. Note: dotted line represents a theoretical ratio of change in horizontal stress to pore-pressure ΔSh/ΔP=α(1-2v)/(1-v), for the ideally thin, laterally extensive reservoir based on poroelasticity (Rutqvist, 2012; α=1 and ν=0.15 in this study).