Numerical simulation of pressure and CO_2 saturation above an imperfect seal as a result of CO_2 injection: implications for CO_2 migration detection

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ABSTRACT

A numerical model was developed with funding support from National Risk Assessment Partnership (NRAP), U.S. DOE to simulate pressure and CO_2 saturation evolution in a porous and permeable interval (AZMI) overlying an imperfect primary seal of a geologic CO_2 storage formation. The seal imperfection is modeled as a single higher permeability zone in the otherwise low permeability seal, with the center of that zone 1,400 m away from the CO_2 injection well. The simulation showed a circular region of pressure increase of greater than 0.1 MPa (approximately 3 km in diameter) surrounding the high permeability zone at the bottom of the AZMI after 30 years of active CO_2 injection. The diameter of the corresponding CO_2 plume above the seal was about 1 km at the bottom of the AZMI after 30 years of active CO_2 injection. Modeling results suggest that the pressure response from fluid migration allows early detection. The natural logarithm of the amount of CO_2 migration through the high permeability zone can be linearly correlated with an author-defined index named "CO_2 migration index", which can be used to quickly evaluate the amount of CO_2 migration from the primary containment to the overlying formation for different CO_2 storage systems.

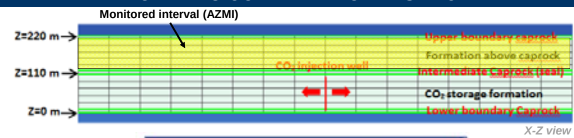
BACKGROUND

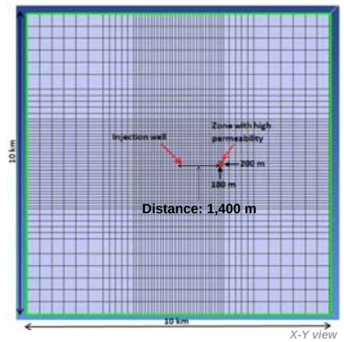
- Deep saline aquifers have the highest CO_2 storage capacity of all candidate geologic storage targets - ~1,738 Gigatonnes of CO_2 in North America alone (The North American Carbon Storage Atlas, 2012).
- CO_2 leakage through caprock may be detected by monitoring pressure and CO_2 saturation response in porous and permeable zones above that caprock.
- This study employs TOUGH2 to simulate CO_2 and brine leakage through fractured caprock. The goal of this study is to answer the following questions: 1) how fast a CO_2 leakage can be detected at the above zone monitoring interval (AZMI) above a fractured caprock; 2) how the permeability change of the fractured caprock affects the amount of leaking CO_2 and the time required to detect the leakage.

MODELING CODE AND MODEL SET UP

- **Modeling code: TOUGH2**
- **Model set up: 3-D model with 37,908 active grid blocks**
- **Eqn-of-state: ECO2N (water, CO_2 and NaCl)**
- **Isothermal simulation with no heat exchange considered**

MODELING CODE AND MODEL SET UP





Model set-up with the location of the fractured caprock (high-permeability zone in red)

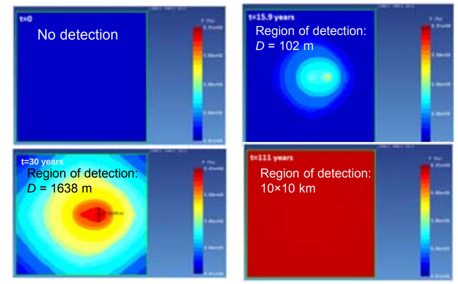
Modeling parameters

Parameter	Value	Parameter	Value
Density of rock in Layers 1-5	2600 kg/m^3	CO_2 injection rate (constant rate from t=0 to t=30 years)	31.7 kg/s (1M tons per year)
Initial pressure at Z=100 m	10.1 MPa	Brine residual saturation	0.025
Pressure gradient	10^4 Pa/m	CO_2 residual saturation	0.1
Temperature	47 °C	Capillary pressure	2×10^4 Pa
Horizontal permeability (storage formation and formation above caprock)	10^{-13} m^2 (0.1 D)	Thickness of caprock layers	10 m
Vertical permeability (storage formation and formation above caprock)	10^{-14} m^2 (0.01 D)	Thickness of the storage formation	100 m
Horizontal permeability (caprock)	10^{-19} m^2 (10^{-7} D)	Thickness of the formation above caprock	90 m
Vertical permeability (caprock)	10^{-20} m^2 (10^{-8} D)	Salt (NaCl) mass fraction in brine	0.1
Horizontal permeability (fractured caprock)	10^{-19} m^2 (10^{-7} D)	Porosity (storage formation and formation above caprock)	0.1
Vertical permeability (fractured caprock)	10^{-17} m^2 (10^{-5} D)		
CO_2 injection period	30 years	Porosity (caprock)	0.05
Post-CO_2 injection period	100 years	Maximum simulation time	130 years
Domain size	10×10 km	Simulation time step	Automatic adjustment (initial step = 100 s)
Boundary condition	Open boundary		

RESULTS

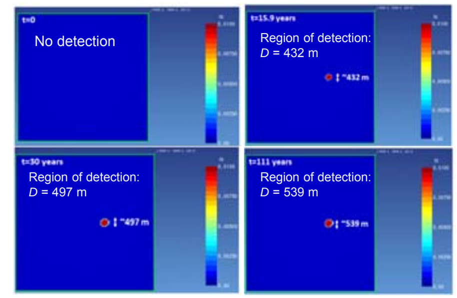
Pressure above the fractured caprock

Detection threshold: $\Delta P = 10^5$ Pa

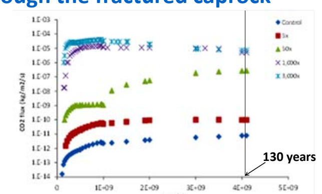


CO_2 saturation above the fractured caprock

Detection threshold: $\Delta S = 0.0025$

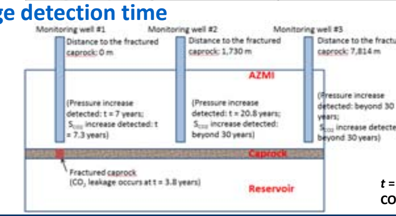


CO_2 flux through the fractured caprock



Scenario	Total amount of CO_2 leaked during 130 years (kg)	Total amount of CO_2 leaked/total amount of CO_2 injected (%)
Control (no fractured seal)	514	1.71E-06
5x higher fractured seal permeability	9.47E3	3.16E-05
50x higher fractured seal permeability	1.29E7	4.28E-02
1,000x higher fractured seal permeability	1.23E9	4.09
3,000x higher fractured seal permeability	2.33E9	7.75

Leakage detection time



t = time elapsed after CO_2 injection begins

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