Vadose Zone Remediation of CO_2 Leakage from Geologic Carbon Sequestration Sites

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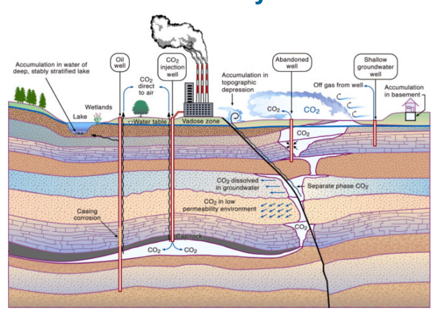
Introduction

- Storage of CO_2 in deep geological formations involves risk that CO_2 will leak upward to the vadose zone.
- The migration of CO_2 through the vadose zone has some similarity to the transport of common vadose-zone contaminants.
- Soil vapor extraction (SVE) technology can be used for the removal of CO_2 from the vadose zone.

Outline

- Potential leakage and seepage pathways.
- Differences relative to other contaminants.
- Modeling methods.
- Review of initial conditions.
- 2D radial results.
- 3D results.
- Conclusions.

Potential Leakage and Seepage Pathways



Terminology

- Leakage = CO_2 migration away from primary sequestration target.
- Seepage = CO_2 transport out of the ground into the atmosphere or into surface water.
- Near-surface environment = ~ 10 m depth – ~ 10 m height.

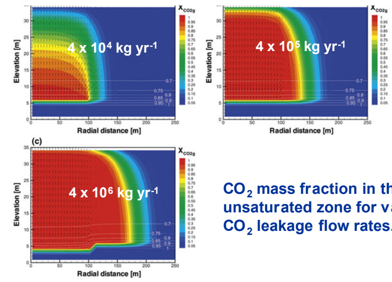
Differences Between CO_2 and Other Gaseous Contaminants

- VOC gas plumes volatilize from NAPLs.
- Potential CO_2 leakage plumes are expected to arrive from below the vadose zone while VOC plumes tend to arrive from above due to leaking tanks and surface spills.
- CO_2 has a higher solubility in water, VOCs are generally much less soluble.
- At low concentrations CO_2 is harmless while VOCs may be toxic.

Methodology

- Numerical simulations were performed using T2CA, a special module of the TOUGH2 simulator.
- A half-life of the CO_2 plume is defined as the time required for one-half of the initial CO_2 mass to be removed from the domain. This is a convenient measure of the CO_2 removal rate.
- The initial CO_2 distribution in the model vadose zone corresponds to a steady-state leakage scenario (Oldenburg and Unger, 2003).

Migration Through 30 m of Vadose Zone with Infiltration 10 cm yr^{-1}



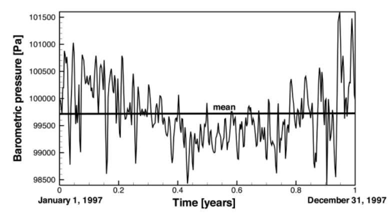
CO_2 mass fraction in the unsaturated zone for various CO_2 leakage flow rates.

(Oldenburg and Unger, *Vadose Zone Journal*, 2, 287–296, 2003)

Remediation Simulations (I)

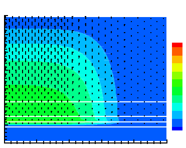
- 2-D Simulations
  - Natural attenuation (passive remediation) without barometric pumping
  - Natural attenuation (passive remediation) with barometric pumping
  - A 30 m length vertical well with screen from height 5 – 20 m
  - A 30 m length vertical well with an impermeable surface cover of 50 m radius

Barometric Pressure Profile

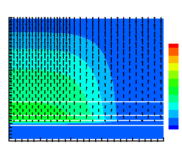


Measured at McClellan AFB, Sacramento, CA.

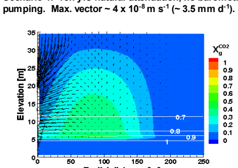
Profile is replicated for multiyear simulations.



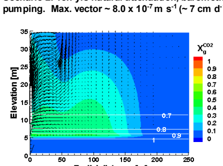
Scenario 1. Ten yrs natural attenuation, no barometric pumping. Max. vector ~ 4 x 10^{-8} m s^{-1} (~ 3.5 mm d^{-1}).



Scenario 2. Ten yrs natural attenuation, barometric pumping. Max. vector ~ 8.0 x 10^{-7} m s^{-1} (~ 7 cm d^{-1}).

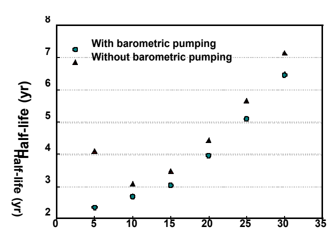


Scenario 3. After 10 yrs extraction. Max. vector ~ 4.5 x 10^{-4} m s^{-1} (~ 40 m d^{-1}).



Scenario 4. After 10 yrs extraction with a cover. Max. vector ~ 4.5 x 10^{-4} m s^{-1} (~ 40 m d^{-1}).

2-D Half-life Comparison



Half-life for different vadose zone thicknesses, passive remediation.

Remediation Simulations (II)

- **3-D Simulations**
  - Scenario 1. Vertical well only, well screen is from 20 m – 30 m
  - Scenario 2. Horizontal wells only. Length is 90 m aligned with the x- and y-axes at a height of 20 m above the bottom of the domain
  - Scenario 3. Both vertical and horizontal wells (i.e., combination of Scenarios 1 and 2)

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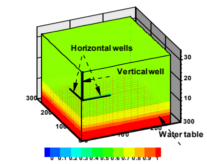
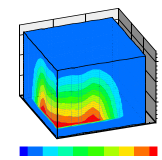
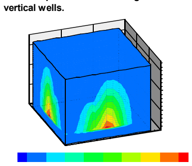


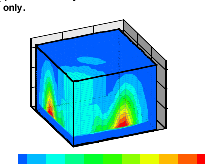
3D conceptual model showing horizontal and vertical wells.



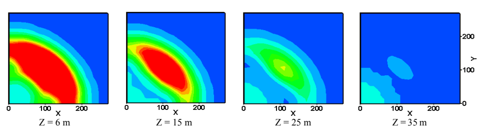
CO_2 plume after 10 years of extraction with the vertical well only.



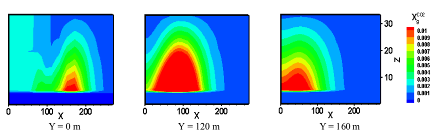
CO_2 plume after 10 years of extraction with the horizontal wells.



CO_2 plume after 10 years of extraction with the both horizontal and vertical wells.

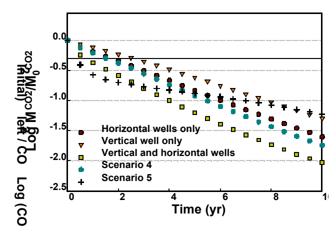


XY-cross section for Scenario 3 (both horizontal and vertical wells).



XZ-cross section for Scenario 3 (both horizontal and vertical wells).

3-D Half-life Comparison



Remaining CO_2 vs. time for different scenarios. The solid horizontal line indicates half-life time.

* Scenario 4 - a longer horizontal well length (120 m) is used with the same total pumping rate.

Scenario 5 - an anisotropy ratio (k_z/k_y, $k_y = k_x$) of 0.1 is used, with horizontal permeability kept unchanged.

Conclusions

- Barometric pumping enhances the removal rate of CO_2.
- Passive CO_2 removal from high-water saturation regions near the water table is limited by low gas saturation and high solubility in groundwater.
- A combination of an impermeable cover and vertical well will improve the removal rate of CO_2 if the well screen is relatively shallow.
- The combination of horizontal and vertical wells is more effective than having one or the other.
- Permeability anisotropy ($k_x > k_z$) results in a faster removal rate at an early stage and slower rate later on.
- Overall conclusion is that large amounts of CO_2 can be removed from the vadose zone by existing SVE technology.

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Acknowledgments

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CO2 Capture Project

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