Non-linear Feedback Processes During CO_2 Leakage Involving a Secondary Accumulation at Shallow Depth

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ABSTRACT

Leakage of CO_2 from a geologic storage reservoir has been simulated for a pathway that includes fault zones and a secondary accumulation in a shallow aquifer. 3-phase flow of aqueous phase - liquid CO_2 - gaseous CO_2 and non-isothermal effects give rise to non-linear feedbacks. CO_2 outflow at the land surface may be preceded by enhanced spring discharge.

The Problem

CO_2 disposal will produce large injection plumes (of order 100 km^2 or more for a 1,000 MWe coal-fired power plant).

On such a large spatial scale, it appears likely that caprock imperfections will be encountered, and some leakage will occur.

Concerns

- Loss of CO_2 from storage
- Potential hazards from CO_2 release { groundwater contamination, asphyxiation, pneumatic eruptions?

Objectives of this Research

- understand dynamics of flow processes during leakage
- explore and assess hazard potential
- identify favorable/unfavorable conditions

Approach

- screen/identify hydrogeologic conditions of concern
- identify "troublesome" scenarios
- set up conceptual models for leakage
- perform numerical simulations
- understand system dynamics and controls

Issues

- multiphase fluid flow
- non-isothermal effects
- phase change: liquid <==> gaseous CO_2
- super- and sub-critical fluid

Self-enhancing feedbacks?

CO_2 compared to water is

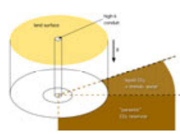
- less viscous ==> more mobile
- less dense ==> pressure increases at shallow horizons
- much more compressible ==> large expansion during depressurization

Feedback processes

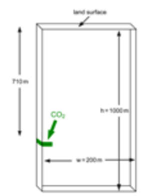
- exsolution from aqueous phase can cause large volume expansion
- volumetric expansion of CO_2 causes cooling which increases density
- interference between different phases reduces fluid mobility, increasing both CO_2 pressure and accumulating inventory of CO_2
- mineral dissolution can increase ϕ, k (porosity, permeability)
- pressurization from injection can induce movement along faults with increases in ϕ, k

Leakage Scenarios

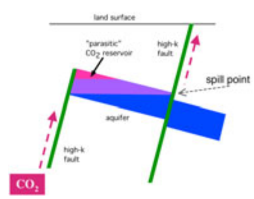
High-permeability conduit (well)

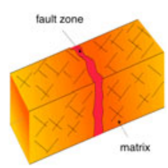


Idealized fault zone

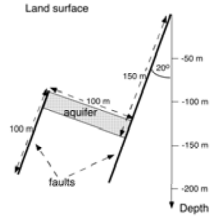


Fault or fracture zones





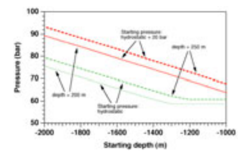
Reference Case (model a 1 m thick slice)



Potential for Self-Enhancement

After the spill point is reached and upflow/outflow commences, expect **increased fluid mobility** accompanied by **depressurization**, and large volumetric **expansion**.

For CO_2 as pressure controlling phase, large overpressures can be generated at shallow depths

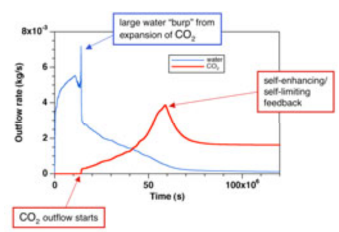


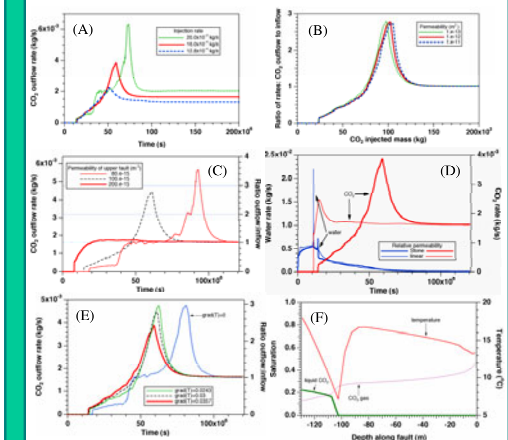
The figure shows pressures in static columns of CO_2 at 200 and 250 m depth, versus the depth at which the columns start. Starting pressures are either hydrostatic or hydrostatic + 20 bar, and temperatures along the columns follow a "normal" geothermal gradient (30 °C/km).

Simulation Conditions and Results

- start from water-saturated conditions, geothermal-hydrostatic equilibrium
- use TOUGH2/EOSM for mixtures of water with sub- and supercritical CO_2, including phase transitions and latent heat effects
- inject CO_2 at constant rate
- CO_2 displaces water and partially dissolves
- CO_2 accumulates in the aquifer
- depending on injection rate, pressures may exceed saturated values, and three-phase conditions may develop (aqueous - liq. CO_2 - gaseous CO_2)
- after spill point is reached, get two and three-phase flow towards land surface
- upward flow of CO_2 is accompanied by decompression and cooling (Joule-Thomson effect, boiling of liquid CO_2)
- important role of conductive heat transfer from the wall rocks

Outflow behavior





(A) CO_2 outflow for different injection rates
(B) approximate invariance to rate/permeability
(C) dependence of CO_2 outflow on permeability of upper fault (F = 16.e-4 kg/s)
(D) sensitivity to 3-phase rel.perms. (F = 16.e-4 kg/s)
(E) sensitivity to geothermal gradient (F = 16.e-4 kg/s)
(F) CO_2 saturations and temperatures in top fault zone after 1.5 years (20.e-4 kg/s)

Concluding Remarks

- CO_2 outflow may be preceded by enhanced spring discharge
- larger permeability in the outflow channel (fault) will facilitate CO_2 discharge but will also reduce CO_2 accumulation
- self-enhancing and self-limiting feedbacks depend on flow rate in highly non-linear fashion
- enhancements of land surface discharge are modest on a mass basis (of order 3) but may be very large on a volumetric basis
- three-phase flow and non-isothermal effects can be important

Reference

Pruess, K. On CO_2 Fluid Flow and Heat Transfer Behavior in the Subsurface, Following Leakage from a Geologic Storage Reservoir, *Environmental Geology*, in press, 2007.

Acknowledgement

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