Thermal Effects Associated with CO_2 Injection in the Integrity of Bounding Seals

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Outline

- Introduction
- Analysis Procedure
- Thin and Thick Reservoirs
- Results of Simulations
- Observations from Study

Introduction

- The thermo-mechanical behavior of a saturated porous media is important for processes such as geothermal energy extraction, thermal stimulation of hydrocarbon reservoirs, nuclear waste disposal, and borehole stability
- The study of coupled T-H-M effects has shown the strong coupling between heat flow, fluid flow, and solid matrix deformation

Temperature and Geological Storage

- Require a dense stream of CO_2 at the wellhead, a condition that is easily achieved by cooling off the CO2
- Once CO_2 is injected into the reservoir, it requires the addition of heat to reach in-situ conditions - inducing temperature gradients around the injector
- In light of this established coupling response associated with the injection of a cooler stream of CO_2, the integrity of the sink and its bounding seals becomes a potentially important consideration

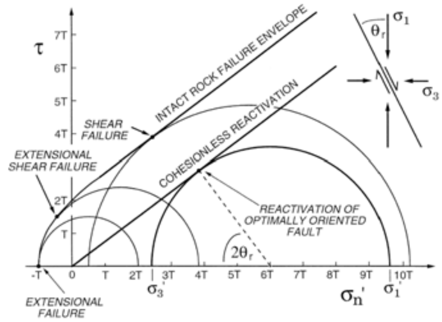
Analysis Procedure

- Coupled heat – flow equations are solved in TOUGH2, assuming the formation fluids are CO_2 saturated
- The CO_2 equation of state (EOS) proposed by Span and Wagner is used. The simulation treats the injection of pure CO_2 with an enthalpy content of -300 kJ/kg into a reservoir filled with CO_2
- Temperature and pressures are imported into FLAC 4.0 to solve the geomechanical evolution (stress changes) of the system

Geomechanical Analyses

- A hydrostatic stress condition is assumed (ie $\sigma_h' = \sigma_v'$)
- Elastic and plastic analyses are carried out.
- For the plastic analysis, the Mohr-Coulomb failure criteria (assuming a tensional strength equal to 10% of the cohesion)

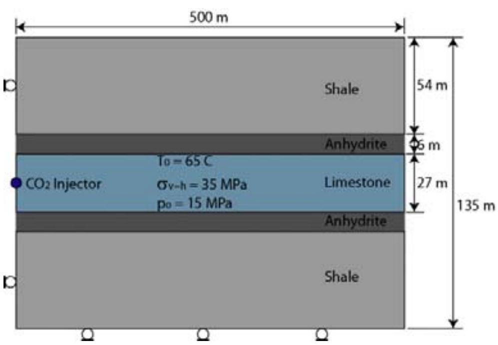
Mohr-Coulomb and Hydrofracturing



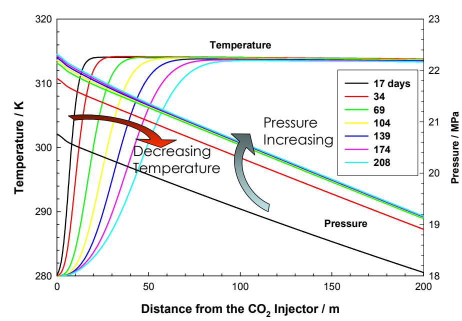
Thin and Thick Injection Horizons

- Thin Reservoir:
  - Depth of 1500 meters
  - Composed of a 27 m carbonate reservoir and bounding seals of anhydrite and shales
  - An in-situ temperature of 313 K
  - CO_2 is injected at a rate of 0.05 kg/s per meter
- Thick Reservoir :
  - Depth of 1500 meters
  - Composed of a 100 m thick sandstone capped by thick shales
  - An in-situ temperature of 320 K
  - CO_2 is injected at a rate of 0.05 kg/s per meter

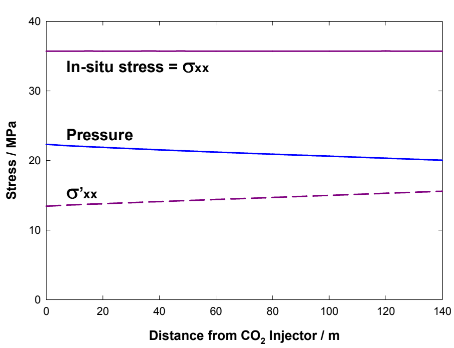
Thin Reservoir



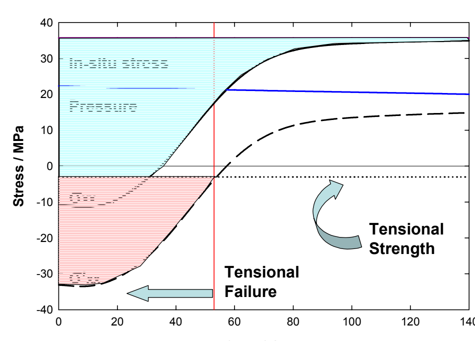
Temperature & Pressure Profiles



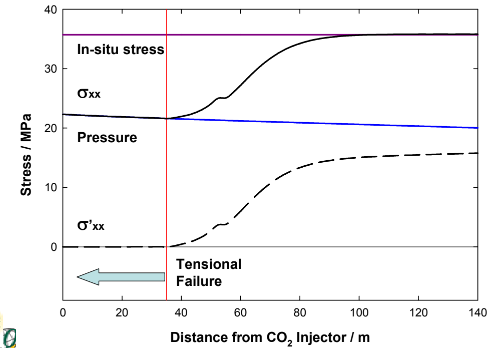
Isothermal: t=208 days



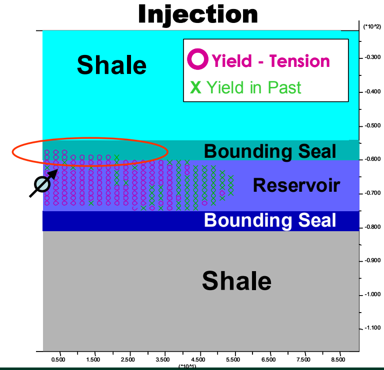
Non-Isothermal Elastic: t=208 days



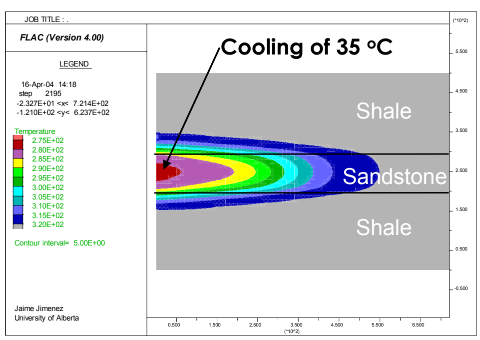
Non-Isothermal Plastic: t=208 days



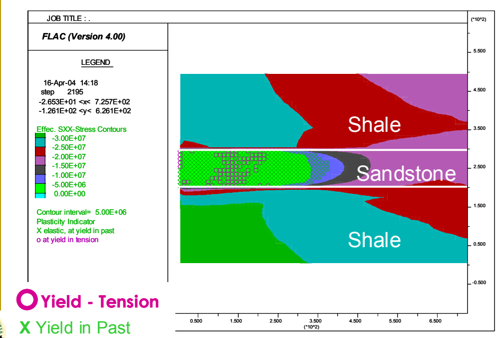
Failed Zones after 208 days of Injection



Thick Reservoir – Temperature at 20 years



Horizontal Effective Stress: t=20 yrs



Observations from Study

- Clearly cold injection can lead to fracturing (tensile failure) of the injection horizon, however modeling from a continuum to a discontinuum is complex
- Multiphase flow, which is necessary, will make the modeling even more complex because of lack of understanding of flow of multiple phases in fractures and the evolution of fractures during the injection history

Observations from Study

- Knowledge of fracture propagation mechanisms under these injection conditions is fundamental to know whether the bounding seals are affected
- There is the need for a better understanding of how low porosity rocks react to cooling –*hydromechanically speaking*!

Observations from Study

- Cool injection of CO_2 changes substantially the in-situ stress field, and may potentially affect the hydraulic integrity of the bounding seals
- Evolving stress fields and pressure distributions may lead to hydraulic fracturing conditions of bounding seals – ***careful control of injection pressures under these conditions!***

Observations from Study

- Research is continuing on more realistic and rigorous methods to analyze the problem
- Measurements during field experiments – don't underestimate temperature as a monitoring variable…..
- Initial in-situ stresses are a fundamental input to know if cool injection streams of CO_2 can lead to integrity issues within the bounding seals of a geological storage horizon

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