Assessing the Effective CO$_2$ Storage Capacity of a Reservoir Using a Geomechanical Framework

A case study of a site in the Arches Province of the Midwest U.S.
Outline

- Background
  - CO₂ storage in deep saline aquifers
  - Injection-induced stress changes in the reservoir

- Modeling the Arches Province Site
  - Methodology: workflow, model construction, assumptions
  - Sensitivity scenarios

- Analysis
  - Geomechanical impacts
  - Effective capacity estimate
CONCEPTUAL REVIEW
CO₂ Storage in Deep Saline Aquifers

- CO₂ injection into an aquifer creates a plume.
- Pressure profile generated.
- All injected CO₂ is stored either in supercritical state or by dissolution into the brine.

Coupled Fluid Flow – Reservoir Geomechanics Simulation

Force

Stress

Pore-Space Deformation

Strain

modified from Tran et al, 2005
Geomechanical Impacts of Injection

Overview

Geologic/Geomechanical Properties

Reservoir Model

Delineated geomechanical units

CO₂ Injection
Mohr Circle Analysis

Total stress increases as a result of injection.
Shear failure is said to occur if the Mohr circle plotted after injection hits the failure envelope.

Distance from the envelope implies minimal risk of fracture activation.

A weak or highly naturally fractured rock has a very low value of rock cohesion.

MODEL DEVELOPMENT
Analysis Framework

Estimates for:
- Permeability/Porosity
- Thickness/Layering
- Geomechanical Parameters
- Other model assumptions

Input

Model Construction

Baseline Simulations

Sensitivity Studies

Additional Modeling

Output

Simulation-ready Reservoir and Geomechanical grids, with Aquifer, Caprock, and Overburden.

Pressure and stress-field response in Aquifer, Caprock, and Overburden for a baseline injection scenario.

Assessment of vertical uplift, risk of shear and tensile failure

Uncertainty bandwidths for geomechanical parameters.

Other site-specific sensitivities (e.g. varying injection rate, boundary conditions, etc.)

Delineated injection scenarios and corresponding models.

Natural fractures

Stress-enhanced permeability

Quantify effective capacity
Arches Province in the Midwest US: East Bend Well Site
Model Construction

- 25,000 Acres
- 1000 x 1000 ft
- Grid refinement around Injector
- 30 years of injection

- Collocated Geomechanical and Reservoir grids
- Middle Run (underburden) to Surface.
- Log or literature-based stress gradients, static Young's modulus, Poisson's ratio

- Davis overlying the Eau Claire overlying the Mt. Simon
  - 0.733 psi/ft injection limit or 2500 psi in Mt Simon.
  - Assumptions for relative perm, homogeneity, etc.

Collocated Geomechanical and Reservoir grids

Middle Run (underburden) to Surface.

Log or literature-based stress gradients, static Young's modulus, Poisson's ratio

Davis overlying the Eau Claire overlying the Mt. Simon

- 0.733 psi/ft injection limit or 2500 psi in Mt Simon.
- Assumptions for relative perm, homogeneity, etc.
Characterization: Permeability

- Pressure Transient-Analysis on 3 brine injection fall-off tests
- ~1000 ft radius of investigation

Characterization: Minimum Horizontal Stress

Log, mini-frac test data and literature-based regional geomechanical trends enable constraining the stress in the Mt. Simon.

## Sensitivity Scenarios

<table>
<thead>
<tr>
<th>Scenario #</th>
<th>Boundary Condition</th>
<th>Biot’s Coefficient</th>
<th>Young’s Modulus</th>
<th>Max. Horizontal Stress Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Base Case (Most Conservative)</td>
<td>Closed</td>
<td>1</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>2.</td>
<td>Closed</td>
<td>1</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>3.</td>
<td>Closed</td>
<td>1</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>Closed</td>
<td>0.8</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>5 (Most Optimistic)</td>
<td>Open</td>
<td>0.8</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
RESULTS AND ANALYSIS
Injection into the Mount Simon: CO$_2$ Volumes and Pressure Increase

- Δ$p$ of ~900 psi in the Mt. Simon.
- Δ$p$ of ~725 psi in the Eau Claire.
- Approx. 11.25 million MT of CO$_2$ stored.
- ~1 million MT of CO$_2$ migrates upward into the Eau Claire.
Injection into the Mount Simon: CO₂ Plume and Pressures Attained

Gas Saturation

CO₂ plume is around ~5000 ft wide and penetrates up to lower Eau Claire.

Pressure

Lower Eau Claire pressure increases to ~2300 psi.
Injection into the Mount Simon: Stress-Strain Impact

$\Delta$ Min. Effective Stress

Volumetric Strain

Reduction in effective stress is more pronounced in lower Eau Claire.

Pore-space deformation occurs mostly in the Eau Claire and Mt. Simon.
Injection into the Mount Simon: Localized Stress Effects

- The minimum effective stress-profile from the underburden to the surface before and after injection.

- Negligible impact on layers caprock and above.
Injection into the Mount Simon: Surface Uplift

Areal Displacement

Near uniform uplift across 25,000 acres at the end of injection.

Areal Displacement w.r.t. CO₂ Volume

Surface uplift of approx. 32 mm with ~11.25 million MT of injection.
Injection into the Mount Simon: Caprock Integrity (Davis)

Principle Effective Stresses

Mohr Circle
No shear or tensile failure.

Stresses in caprock are unchanged.
Injection into the Mount Simon: Intermediate Zone Integrity (Eau Claire)

**Principle Effective Stresses**

- Vertical stress affected more than horizontal.
- Regime change after 8 years of injection.

**Mohr Circle**

- No shear or tensile failure.

![Graph showing stress changes over years of injection](Image of graph showing stress changes over years of injection)
Injection into the Mount Simon: Reservoir Integrity

Principle Effective Stresses

Mohr Circle

No shear or tensile failure.

Vertical stress affected more than horizontal. No regime change.
## Sensitivity Scenarios

<table>
<thead>
<tr>
<th>Scenario #</th>
<th>Shear Failure?</th>
<th>Tensile Failure?</th>
<th>Surface Uplift (mm)</th>
<th>Storage Capacity (millions of MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 - Base Case (Most Conservative)</strong></td>
<td>No</td>
<td>No</td>
<td>32</td>
<td>11.25</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>No</td>
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<td>3</td>
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<td>No</td>
<td>27</td>
<td>11.25</td>
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<td>4</td>
<td>No</td>
<td>No</td>
<td>22</td>
<td>12.5</td>
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<tr>
<td><strong>5 (Most Optimistic)</strong></td>
<td>No</td>
<td>No</td>
<td>1.2</td>
<td>38.25</td>
</tr>
</tbody>
</table>
Summary

- Simulations suggest minimal risk of tensile or shear failure.
  - Minimum effective stress in all three zones is >500 psi.
  - Even the most conservative shear envelope is sufficiently distant from Mohr’s circles.

- Up to 32 mm of uplift may be expected.

- A stress-regime change may occur in the Intermediate Eau Claire
  - Simulations do any indicate that this poses any threat to the operation.

- Evidence in literature for optimistic modelling conditions.

- Conservative estimate of effective capacity is ~11.25 million MT.
THIS RESEARCH WAS SUPPORTED BY THE U.S. DOE / NATIONAL ENERGY TECHNOLOGY LABORATORY (CONTRACT DE-FE0023330) AND THE OHIO DEVELOPMENT SERVICES AGENCY OHIO COAL DEV. OFFICE (GRANT CDO-D-14-17).