Statistical Analysis of CO\textsubscript{2} Exposed Wells to Predict Long Term Leakage through the Development of an Integrated Neural-Genetic Algorithm

Project DE FE0009284

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Presentation Outline

• Benefits to DOE Program
• Project Overview
• Technical Status
• Accomplishments to Date
• Summary
Benefit to DOE Program

The project conducts research under DOE’s Fossil Energy Research and Development Area of Interest 1, Studies of Existing Wellbores Exposed to CO₂.

The project performs analysis of available industry data to assess risks of well failure by various factors such as age of construction, region, construction materials, incident reports, logging and Mechanical Integrity Testing.

The computer models developed in this project will contribute to the DOE programs’ effort of ensuring 99% CO₂ storage permanence in the injection zone(s) for 1000 years and support the development of Best Practices Manual.
Project Overview
Goals and Objectives

The overall objective of this project is the development of a novel computer model for predicting long-term leakage risks of wells exposed to CO₂.

The final goal is to deliver DOE and public a useful tool for evaluating the risk of long-term leakage of wells in future CO₂ sequestration projects.
Technical Status

- Understanding the problem
- Assessment of well conditions
- Mechanics modeling of wellbore conditions
- Identification of leak scenarios
- Prediction of leakage by Integrated Neural-Genetic Algorithm
1. Incomplete annular cementing job, doesn't reach seal layer
2. Lack of cement plug or permanent packer
3. Failure of the casing by burst or collapse
4. Poor bonding caused by mudcake
5. Channeling in the cement
6. Primary permeability in cement sheath or cement plug

SECONDARY
7. De-bonding due to tensile stress on casing-cement-formation boundaries
8. Fractures in cement and formation
9. Chemical dissolution and carbonation of cement
10. Wear or corrosion of the casing
Assessment of Well Conditions

• Well history data
• Well design data
• Well operation data
• Leak potential analysis
  - Maximum Permissible Pressure (MaxPP)
  - Minimum Permissible Pressure (MinPP)
- Maximum Permissible Pressure (MaxPP)
- Minimum Permissible Pressure (MinPP)

Perfect Cement Collar

Imperfect Cement Collar
Mechanics Modeling of Wellbore Conditions

De-Bonding at Casing-Cement Interface

Radial Fractures in Cement Sheath

De-Bonding at Cement-Formation Interface

Radial Fractures in Formation
Step 1- Loading the model with in-situ stress (horizontal and vertical stresses)

Step 2- Simulating of drilling step by removing wellbore elements and applying mud weight

Step 3- Adding casing elements to the model

Step 4- Adding cement elements to the model

Step 5- Cement hydration, temperature and volume changes

Step 6- Applying mechanical and thermal loads to the cased wellbore
Identification of Leak Scenarios

- Cement properties
- Cement shrinkage
- Injection and shut in of wells
- Initial cement placement operations
- Cement degradation
Prediction of Leakage by Integrated Neural-Genetic Algorithm

- Model construction has been completed
- Model training and validation is in progress
- Prediction with the model is planned
Accomplishments to Date

✓ Data mining

✓ Assessment of well conditions

✓ Identification of leak scenarios with mechanics model

✓ Test site selection

✓ Development of Integrated Neural-Genetic Algorithm
Data Mining in the Texas Gulf Coast Region

- West Hastings and Oyster Bayou oil fields, Texas.
- 510 CO2-exposed wells.
- Data base established
Assessment of Well Conditions

- MaxPP without Fluid Gap of West Hastings Oil Field
- Maximum Water Injection Pressure of West Hastings Oil Field

Pressure (psi) vs. Depth (ft)
MaxPP with Fluid Gap of Oyster Bayou Oil Field

Maximum Water Injection Pressure of Oyster Bayou Oil Field
<table>
<thead>
<tr>
<th>Group No.</th>
<th>Criteria One</th>
<th>Criteria Two</th>
<th>Safety Indicator</th>
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<td>1</td>
<td>S-Csg&lt; H₂O-zone</td>
<td>Cement Top&gt;H₂O-zone</td>
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<td>S-Csg&lt; H₂O-zone</td>
<td>Cement Top&lt;H₂O-zone</td>
<td>1</td>
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<tr>
<td>3</td>
<td>S-Csg&gt; H₂O-zone</td>
<td>Cement Top&gt;H₂O-zone</td>
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<td>4</td>
<td>S-Csg&gt; H₂O-zone</td>
<td>Cement Top&lt;H₂O-zone</td>
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<table>
<thead>
<tr>
<th>Field</th>
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<td>West Hasting</td>
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Identification of Leak Scenarios with Mechanics Model

- Long Term Analysis
  - 4 Scenarios
    - In-Situ Stress Conditions
    - Production Conditions
    - Depletion Conditions
    - Injection Conditions
  - 2 Initial Wellbore Pressures
    - Hydrostatic and U-tube
  - Point of interest is production casing at bottom of sealing formation
• In-Situ Stress Conditions
  – Based on cement annular pressure (open vs closed)
  – Based on formation in-situ stresses
  – Based on internal casing pressure (hydrostatic vs U-tube)
  – Overall no failure

• Production Conditions
  – For gas well pressure equals reservoir pressure
  – Temperature equals reservoir temperature
  – Open U-tube shows greater potential for radial de-bonding
  – Open hydrostatic shows greater potential for tensile fracturing
  – Overall no failure
• Depletion Conditions
  – For gas well pressure equals half reservoir pressure
  – Temperature equals reservoir temperature
  – U-tube scenarios are at greater potential of radial de-bonding
  – Overall no failure

• Injection Conditions
  – Injection temperature change 51°C or 92°F decrease
  – 20MPa or 2.9ksi injection pressure increase above hydrostatic
  – Open annulus U-tube is at the greatest potential of de-bonding
  – Open hydrostatic is at the greatest potential of tensile failure
  – Overall no failure
Potential CO₂ Field Case Study

- Actual Injection Well (Schlumberger Carbon Services)
- Cores gathered along the production section
- Lab samples made to replicate cement composition

### Cement Mechanical Properties Before and After CO₂ Degradation

<table>
<thead>
<tr>
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<th>Poisson's Ratio, $\nu$</th>
<th>Young's Modulus, $E$ (10^6 psi)</th>
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<tr>
<td>Lab Samples</td>
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<td>Aged Cores</td>
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<td>1.245</td>
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</table>
Radial Stress

Hoop Stress

Graphs showing stress levels for different conditions.
Test Site Selection

- Gorgas #1 Well, Walker County, Alabama
- Proximity to oil and gas wells will allow the testing of algorithms developed
• DOE-NETL funded characterization well used for “Site Characterization for CO2 Storage from Coal-fired Power Facilities in the Black Warrior Basin of Alabama” (DE FE0001910)

• Collaboration with other DOE NETL projects

• Well characterized allowing us to focus our resources on collecting well integrity data
Potential Tools for Data Collection

- **Logging Tools**
  - Isolation Scanner* cement evaluation service
  - Sonic Scanner* acoustic scanning platform
  - SCMT* slim cement mapping tool

- **Testing and Sampling Tools**
  - CHDT* cased hole dynamics tester
  - MDT* modular formation dynamics tester
  - MSCT* mechanical sidewall coring tool

[Diagram of wellbore with labels: Perforation for VIT test, CHDT Sample Point, Fluid Sample Point, Point permeability measurement, Sidewall Core Sample, VIT Interval, Wellbore, Well Cement, Geologic Formation]
Well Sampling and Point Permeability Measurement – CHDT

O-ring Seal

7mm Drill Bit

Feet to push O-ring against casing wall
Average Annular Permeability Measurement – MDT
Development of Integrated Neural-Genetic Algorithm

![Graph showing the relationship between Neural Network Output and Well Degradation Ratio with data points for Training and Testing.]
Summary

– Inadequate number of wells were found to have CO2 leakage problems in the Oyster Bayou and West Hasting fields to perform rigorous statistical analysis.

– Risk assessment shows that wells in the Oyster Bayou field are under higher risk of leak than the wells in the West Hasting field.

– A computer model with Integrated Neural-Genetic Algorithm was developed to predict well leak probability.

– A mechanics model was built to predict well leak scenarios. It needs to be validated by test site data.

– A test site has been selected and will be used to verify the computer models.
Appendices

Appendix A – Organization Chart
Appendix B – Gantt Chart
Appendix C – Bibliography
Appendix A – Organization Chart

Principle Investigator
Dr. Boyun Guo
University of Louisiana at Lafayette

CO-Principle Investigator
Dr. Andrew Duguid
Schlumberger Carbon Services

CO-Principle Investigator
Dr. Runar Nygaard
Missouri University of Science and Technology
# Appendix B – Gantt Chart

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<th>Tasks</th>
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<td>2 Data Mining</td>
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<td>3 Statistical analysis</td>
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<td>4 Leakage scenarios development</td>
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<td>5 Preliminary Neural analysis</td>
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<td>6 Neural network analysis</td>
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<td>10 Project risk study and mitigation actions</td>
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Appendix C – Bibliography
