Feasibility of Geophysical Monitoring of Carbon-Sequestrated Deep Saline Aquifers

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Outline

• Benefits to the program
• Project Overview
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Benefit to the Program

• The research project is aimed at:
  – Developing methods to monitor the CO\textsubscript{2} plume movements within the sequestrated reservoir volumes.
  – Account for the totality of the injected CO\textsubscript{2}.

• It serves one of the major goals of the program:
  – Develop technologies to demonstrate that 99 percent of injected CO\textsubscript{2} remains within the injection zones.
Project Overview: Goals and Objectives

- **Project Objectives:**
  - Combine multiphase reservoir simulation with seismic modeling and inversion.
  - Verify if seismic data could be effectively used in predicting CO$_2$ saturation within the sequestrated reservoir volumes.

- **Project Goal:**
  - Develop technologies to demonstrate that 99 percent of injected CO$_2$ remains within the injection zones.
Technical Status

Seismic Waveform Inversion

CO₂ Saturation Prediction

Flow simulation  Seismic simulation
Randomly uncorrelated model:
- CO$_2$ sequestrated at the bottom of the reservoir
- The model shown is 25 years after sequestration
Eolian sand depositional system:

- CO$_2$ sequestered from the bottom of the reservoir
- (a)-(c) the model 5 years after sequestration
- (d)-(f) the model 55 years after sequestration.
Seismic Modeling of the random system:

- The red curve is the finite-difference computed seismic response from the reservoir using the exact reservoir model.
- The blue curve is the computed response where the exact reservoir model is replaced by an equivalent model of a few homogeneous layers.
- For the random system, the equivalent layers were all isotropic.
Seismic Modeling of the eolian system:
- The red and blue curves are the same as they were for the random
- The equivalent layers needed to be anisotropic.

Take-away message:
- CO₂ sequestration into realistic reservoir systems induce apparent anisotropy in the observed time-lapse seismic responses.
- For an accurate strategy for MVA, the seismic anisotropy cannot be ignored.
Equivalent anisotropic models could reasonably predict CO$_2$ saturation.

**Take-away messages:**
- If time lapse seismic data could be inverted for anisotropic elastic properties →
  - Equivalent anisotropic properties can potentially predict the CO$_2$ saturation
- Important elements to a successful MVA →
  - Anisotropic seismic inversion
  - Calibration of seismic inversion with flow simulation
Technical Status - Seismic Waveform Inversion

Red Curves → True model
Blue Curves → Inverted model
Black (dashed) curves → Search window
Technical Status- Anisotropic Inversion

Take-away messages:

• Time-lapse seismic data could be inverted for anisotropic properties of the sequestrated reservoir volumes.
• These extracted anisotropic properties could then be used to predict CO$_2$ saturation within the reservoirs.
• Multicomponent seismic data are required for an accurate extraction of elastic parameters and density from data.
Accomplishments to Date

• Prestack waveform inversion (PWI) methodology:
  – Isotropic PWI is complete.
  – A prototype anisotropic PWI is developed and is being tested.

• Demonstration of a complete workflow:
  – Calibrating seismic simulations with reservoir flow modeling.
  – Predicting the saturation of the injected CO$_2$ during the post-sequestration phases.
Summary

• Key Findings
  – Saturation of the injected CO$_2$ could be predicted by a proper calibration of seismic simulations with reservoir flow modeling.

• Lessons Learned
  – CO$_2$ injection induces anisotropy in observed seismic responses
  – A correct MVA strategy should include:
    • Acquisition and inversion of multicomponent seismic data
    • Flow modeling and calibration of seismic data with simulation models.
    • Anisotropic inversion for prediction of CO$_2$ saturation
PWI Example – Real data from South China Sea

CMP Number

Initial Model

Inverted Model

Depth (km)

Vp (m/s)

8920  9000  9100  9200  9300  9400

0.2  0.4  0.6  0.8  1.0
Data Prediction (before inversion)

CMP Number

Time (s)

Real Stack

Synthetic Stack
Data Prediction (after inversion)

Real Stack

Synthetic Stack
Drainage and imbibition curves → Minnelusa formation, an analog of the Tensleep formation of the Rock-Spring uplift
Summary

• Future Plans
  – Saturation experiments with Rock-Springs core samples.
  – Flow modeling on Rock-Springs reservoir models.
  – Seismic simulations on Rock-Springs reservoir models and calibrate observed responses with the CO$_2$ saturation within the reservoir.
  – Complete the development of an anisotropic PWI.
  – Demonstrate application of anisotropic PWI on (synthetic) time-lapse seismic data in predicting the CO$_2$ saturation during the post-injection phases.
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