Storage of CO$_2$ in Multi-phase Systems Containing Brine and Hydrocarbons
Project Number: LANL FE-890-18-FY18

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Presentation Outline

- Project Objective
- Approach & Technical Status
- Project Summary
- Synergy Opportunities
Project Objective

• Develop improved quantitative relationships for predicting storage and trapping efficiencies in environments where both a brine and hydrocarbon fluid are present (primarily, unconventional reservoirs such as ROZs).
  ➢ Identify key characteristics
  ➢ Develop empirical models for quantifying: CO₂ storage capacity, oil recovery potential, CO₂ fate
  ➢ Assess CO₂ storage capacity and associated oil recovery for different ROZ fields
  ➢ Focused on greenfield ROZs with potential applicability to other unconventional settings such as brownfield ROZs.
CO₂ Storage in Residual Oil Zones

- Residual Oil Zones (ROZs) are defined as those zones where oil is swept over geologic time period (natural flush) and exists at residual saturation
  - Brownfield: ROZ underlies a Main Pay Zone (MPZ)
  - Greenfield: no Main Pay Zone above ROZ

- ROZs are being increasingly exploited using CO₂-EOR:
  - Multiple on-going commercial field operations in Permian Basin

- Greenfield ROZs can be potentially explored for CO₂ storage with a side benefit of incremental oil recovery

Map source: http://melzerconsulting.com/maps/
Approach & Technical Status

• **Approach:**
  - Utilize numerical simulations using Eclipse compositional simulator
  - Develop empirical models for CO$_2$ storage capacity, oil recovery, CO$_2$ fate using results of numerical simulations
  - Apply empirical models to fields with ROZ

• **FY17 Outcomes:**
  - Developed numerical models based on field data from Permian Basin
  - Performed initial characterization of CO$_2$ storage in ROZs
**FY18: Numerical simulations**

- Reservoir model based on data for Goldsmith-Landreth San Andres Unit (GLSAU) in the Permian Basin: ARI study, History matched
- Monte-Carlo simulations: 15 years operation (10 years injection, 5 years post-injection)
- Multiple uncertain parameters
- Multiple injection modes: Continuous CO$_2$ and WAG
- Multiple well patterns: five-spots (sparse, dense), line drives
- Two ML algorithms for empirical model development: SVR & MARS

<table>
<thead>
<tr>
<th>Uncertain parameters</th>
<th>Lower bound</th>
<th>Upper bound</th>
<th>Units</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (h)</td>
<td>50</td>
<td>300</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>Depth (D)</td>
<td>4000</td>
<td>6000</td>
<td>ft</td>
<td></td>
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<tr>
<td>Permeability (K)</td>
<td>0.01</td>
<td>200</td>
<td>mD</td>
<td>$\phi = 0.082 \times K^{0.216}$</td>
</tr>
<tr>
<td>Sorw</td>
<td>0.2</td>
<td>0.4</td>
<td>--</td>
<td>$P = 14.7 + 0.433 \times D$</td>
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<tr>
<td>Sorg</td>
<td>0.1</td>
<td>0.2</td>
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<td>$T = 60 + 0.015 \times D$</td>
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<tr>
<td>CO$_2$ injection rate</td>
<td>5</td>
<td>20</td>
<td>MM scf/day</td>
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</tr>
<tr>
<td>Producer BHP</td>
<td>100</td>
<td>1500</td>
<td>psi</td>
<td></td>
</tr>
</tbody>
</table>
Key characteristics affecting CO$_2$ storage & oil recovery

Favorable: Production BHP > Injection Rate > Thickness

Unfavorable: Permeability > Depth

Injection Rate > Thickness > Permeability
Sorw > Production BHP
Empirical model application to real fields

• Previous studies on Permian Basin fields (simulation based)
  ➢ Focused on oil recovery
  ➢ Little information on field-specific CO₂ storage capacity

• Limited data in public literature
  ➢ Values of some critical parameters not reported: CO₂ injection rates, permeability

• ML-based empirical models applied to 5 Permian basin fields (reported in ARI study)
Empirical model application to Permian Basin fields

Cumulative Oil Recovery

Cumulative CO₂ Storage

Empirical Models
ARI Study

Empirical Models
ARI Study

None
• Significant fraction of retained CO$_2$ exists as dissolved in oil-phase
• Comparatively, very little fraction of injected CO$_2$ dissolves in water
Comparing CO₂ storage in ROZ, saline aquifers and oil reservoirs

Varied initial oil saturation: 0.7, 0.6, 0.5, 0.4 (=S₀ᵣ, ROZ), 0 (saline aquifer)

Well pattern: Single five-spot

Injection rate: 233 tons/day/well, 933 tons/day/well
Comparing CO$_2$ storage in ROZ, saline aquifers and oil reservoirs

Solid line - Sio=0.7, 0.6, 0.5 or 0.4
Dashed line - Sio = 0
• **Key Findings:**
  
  - Numerical simulations have been used to identify key characteristics as well as develop empirical models for quantifying preliminary CO$_2$ storage capacity, oil recovery potential in ROZs
    - ROZs potentially have significant CO$_2$ storage capacity
    - Field-specific studies needed to improve predictions & predictive capabilities
  
  - Modeling results show that CO$_2$ primarily resides as dissolved in oil-phase or free-phase. Only a little fraction of CO$_2$ is retained in in-situ water phase
  
  - Preliminary modeling studies have been performed to compare CO$_2$ storage between saline reservoirs and reservoir with hydrocarbons at or above residual oil saturations
Project Summary

• Key Findings (contd.):
  - In spite of increased commercial CO₂-EOR operations in ROZs, critical understanding needs to be developed for CO₂ storage & oil production mechanisms as well as long-term CO₂ fate and risks
    - Lack of appropriate data
    - Large uncertainty

• Next Steps:
  - Contribute to NETL initiative on developing ROZ CO₂ storage capacity estimates: Compare modeling results with other efforts
  - Apply empirical models to ROZs from other basins in US
  - Continue work on comparison between CO₂ storage in saline aquifers and reservoirs with hydrocarbons
  - Laboratory experimental characterization of parameters/processes in ROZ
Synergy Opportunities

- NETL Carbon Storage Atlas project: share empirical models for estimating storage capacity
- Other modeling efforts on ROZ storage potential: compare modeling approaches, share results, share lessons learned
- Collaborations and knowledge-sharing with NETL, Illinois Geologic Survey, UT-BEG, UND-EERC
Appendix

- These slides will not be discussed during the presentation, but are mandatory.
Benefit to the Program

• Program goals being addressed:
  – Support industry’s ability to predict CO₂ storage capacity in geologic formations with ±30%.

• Project benefit:
  – This project is focused on developing the science basis to characterize CO₂ storage potential in Residual Oil Zones (ROZs). The objective is to help develop a methodology to estimate CO₂ storage capacity, potential oil recovery and long-term fate of CO₂ that is applicable to a wide range of geologic and operational conditions. This will help CO₂ storage program goal of supporting industry’s ability to predict CO₂ storage capacity.
Project Overview

Goals and Objectives

• Develop improved quantitative relationships for predicting storage and trapping efficiencies in environments where both a brine and hydrocarbon fluid are present (primarily, unconventional reservoirs such as ROZs).
  ➢ Identify key characteristics
  ➢ Develop empirical models for quantifying: CO\textsubscript{2} storage capacity, oil recovery potential, CO\textsubscript{2} fate
  ➢ Assess CO\textsubscript{2} storage capacity and associated oil recovery for different ROZ fields
Organization Chart

• Rajesh Pawar, PI
• Bailian Chen, Post-doc
• George Guthrie, LANL Program Manager
1. Preliminary estimates of CO2 storage potential in representative ROZs across US with associated uncertainties.
2. Empirical model to estimate CO2 storage and utilization potential in ROZs.
3. Re-assessment of ROZ potential in conjunction with CO2 storage.
4. Strategy to explore uncertain parameters in ROZ fields through core scale experiments.
5. Empirical models for applications to estimate CO2 storage capacity, long-term fate and oil recovery potential from ROZs including identification of potentially impactful uncertain parameters.
6. Application of empirical models to fields with ROZs.
7. Initial Experiments.
8. Update empirical models based on experimental results.
9. Application of updated empirical models to ROZ fields through synergistic collaborations.

**Key Accomplishments/Deliverables**

- **2016**: Successfully developed empirical relationships for estimating CO2 storage capacity, oil recovery potential in ROZs.
- **2017**: Quantified CO2 storage capacity, oil recovery potential in multiple ROZ fields in the Permian Basin. Identified key uncertainties associated with CO2-brine-hydrocarbon interactions in ROZ fields.

**Value Delivered**

- Empirical models that can be used to quantify CO2 storage capacity, oil recovery potential in ROZ fields and long-term risks in CO2-brine-hydrocarbon systems.
- Reduction in uncertainties in knowledge base related to ROZs.

*FY of Performance

**FY of funds (Note: funds normally become available mid- to late-FY)
Bibliography
