Enhanced Analytical Simulation Tool for CO$_2$ Storage Capacity Estimation and Uncertainty Quantification

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Presentation Outline

• Project Overview
  – Goals and Objectives
• Technical Status
• Accomplishments to Date
• Synergy Opportunities
• Project Summary
• Future Plans
Project Overview
Goals and Objectives

• Goals
  – Support industry to predict CO$_2$ storage capacity in geologic formations to within ±30 percent.
  – Develop an Enhanced Analytical Simulation Tool (EASiTool) for simplified reservoir models to predict storage capacity of brine formations (open or closed boundary).

• Objectives
  – Provide fast, reliable and science-based estimate of storage capacity.
  – Integrate analytical/semi-analytical geomechanical models
  – Integrate brine extraction models.
  – Provide sensitivity analysis.
Technical Status

- Task 2, 3 and 4 completed.
- General geometry/pattern completed.
- More verification and application.

Diagram:

- Task 2: Development of Pressure Buildup Models
- Task 3: Integration of Rock Geomechanics
- Task 4: Integration of Active Reservoir Management

Outputs:
- Reservoir Storage Capacity
- Number of Required Wells
- Uncertainty Quantification of the Results
Accomplishments to Date

– Finding the optimized rate to maximize storage capacity

\[
\begin{aligned}
\frac{1}{2} \left( \ln(t_D) + 0.80908 \right) + S_a &- \frac{1}{2} \frac{\lambda_g}{\lambda_w} E_i \left( \frac{r_{D1-2}^2}{4 \eta_{D3} t_D} \right) - \frac{1}{2} \frac{\lambda_g}{\lambda_w} E_i \left( \frac{r_{D1-3}^2}{4 \eta_{D3} t_D} \right) \\
- \frac{1}{2} \frac{\lambda_g}{\lambda_w} E_i \left( \frac{r_{D2-1}^2}{4 \eta_{D3} t_D} \right) &- \frac{1}{2} \frac{\lambda_g}{\lambda_w} E_i \left( \frac{r_{D2-3}^2}{4 \eta_{D3} t_D} \right) \\
- \frac{1}{2} \frac{\lambda_g}{\lambda_w} E_i \left( \frac{r_{D3-1}^2}{4 \eta_{D3} t_D} \right) &- \frac{1}{2} \frac{\lambda_g}{\lambda_w} E_i \left( \frac{r_{D3-2}^2}{4 \eta_{D3} t_D} \right) \end{aligned}
\]

\[
\begin{bmatrix}
q_1 \\
q_2 \\
q_3
\end{bmatrix} = \begin{bmatrix}
\frac{2 \pi h k_{rg}}{\mu_g} \\
\frac{2 \pi h k_{rg}}{\mu_g} \\
\frac{2 \pi h k_{rg}}{\mu_g}
\end{bmatrix} \Delta P_{\text{max}}
\]

\[P_{\text{frac}} - P_i\]
Accomplishments to Date

– Calculations for maximum injection pressure added to EASiTool.
– Integrates thermal and pore pressure stresses.

• Normal fault system

\[ P_{\text{max}} = \frac{1}{2\alpha - \beta_v - \beta_h - (\beta_v - \beta_h) \cos 2\theta + (\beta_v - \beta_h) \sin 2\theta / \mu}, \]

\[ \left[ \left( 1 + K \right) + (1 - K) \cos 2\theta - (1 - K) \sin 2\theta / \mu \right] \sigma_{\nu_0} - \left( \beta_v + \beta_h \right) \cos 2\theta - (\beta_v - \beta_h) \sin 2\theta / \mu \right] P_{\text{pi}} - \frac{2\alpha T E \Delta T}{1 - 2\nu} \]

• Reverse fault system

\[ P_{\text{max}} = \frac{1}{2\alpha - \beta_h - \beta_v - (\beta_h - \beta_v) \cos 2\theta + (\beta_v - \beta_h) \sin 2\theta / \mu}, \]

\[ \left[ \left( K + 1 \right) + (K - 1) \cos 2\theta - (K - 1) \sin 2\theta / \mu \right] \sigma_{\nu_0} - \left( \beta_h + \beta_v \right) \cos 2\theta - (\beta_h - \beta_v) \sin 2\theta / \mu \right] P_{\text{pi}} - \frac{2\alpha T E \Delta T}{1 - 2\nu} \]

• Strike-slip fault system

\[ P_{\text{max}} = \frac{1}{ \alpha - \beta_h } \left[ \left( \frac{1 + K_H}{2} + \frac{1 - K_H}{2} \cos 2\theta - \frac{1 - K_H}{2} \sin 2\theta / \mu \right) \sigma_{\nu_0} - \beta_h P_{\text{pi}} - \frac{\alpha T E \Delta T}{1 - 2\nu} \right] \]
Accomplishments to Date

– Finding the optimized rate to maximize storage capacity

\[
\begin{align*}
\frac{1}{2} \left( \ln(t_D) + 0.80908 \right) + S_a & - \frac{1}{2} \left( \frac{r_{D1}^2}{4t_{D,Ext}} \right) - \frac{1}{2} \left( \frac{r_{D2}^2}{4t_{D,Ext}} \right) - \frac{1}{2} \left( \frac{r_{D3}^2}{4t_{D,Ext}} \right) \\
- \frac{1}{2} \frac{\lambda_g}{\lambda_w} E_i \left( - \frac{r_{D2}^2}{4\eta_{D3} t_D} \right) & - \frac{1}{2} \frac{\lambda_g}{\lambda_w} E_i \left( - \frac{r_{D3}^2}{4\eta_{D3} t_D} \right) \\
- \frac{1}{2} \frac{\lambda_g}{\lambda_w} E_i \left( - \frac{r_{D3}^2}{4\eta_{D3} t_D} \right) & - \frac{1}{2} \frac{\lambda_g}{\lambda_w} E_i \left( - \frac{r_{D3}^2}{4\eta_{D3} t_D} \right)
\end{align*}
\]

\[
\begin{pmatrix}
q^1 \\
q^2 \\
q^3
\end{pmatrix}
\]

\[
\begin{pmatrix}
P_{Ext} - P_i \\
\frac{2\pi \eta h k_{r_w} \Delta P_{max}}{\mu_g} \\
\frac{2\pi \eta h k_{r_w} \Delta P_{max}}{\mu_w}
\end{pmatrix}
\]
Accomplishments to Date

– Development and improving user interface
Accomplishments to Date

- Model verification
Accomplishments to Date

- User defined locations for injection and extraction wells
  - Adding multiple reservoirs within the same basin
  - Global pressure maps
Accomplishments to Date

- User defined locations for injection and extraction wells
  - Adding multiple reservoirs within the same basin
  - Global pressure maps
Accomplishments to Date

- Application to the USGS database
  - EASiTool after 1000 years is similar to USDOE 1%.
  - USGS estimation is higher (close to USDOE 4%).
  - EASiTool results after 25, 50, 100, and 1000 years are different.
Synergy Opportunities

– EASiTool is an analytical simulation tool for capacity estimation in saline aquifers.

– Input data required for EASiTool is typically available for most of the projects.

– EASiTool results can be compared with the results obtained in other projects via other methods (static, simulation, etc).
Project Summary

– Fourth version of EASiTool is ready for release.
– EASiTool can be applied to large databases.
– EASiTool is available for download:
  • http://www.beg.utexas.edu/gccc/EASiTool/
Future Plans

– Improving the user interface
– Application to the USGS onshore database (36 Basins)
– Application to the offshore database
– Funding to maintain and further develop EASiTool
Questions
Appendix

– Organization Chart
– Gantt Chart
– Bibliography
Organization Chart

- Young
  - BEG AD
    - Hovorka
      - Nicot
        - BEG Administration
      - Sun
        - (Co-PI)
    - Hosseini
      - (PI)
        - Postdoctorate/s Scholar
        - C12 Energy
          - (Collaborator)
            - van Nierop
# Organization Chart

**Project PI:**
Seyyed A. Hosseini

<table>
<thead>
<tr>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Task 4</th>
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<tr>
<td><strong>Task Leader/Backup</strong> Nicot/Hosseini</td>
<td><strong>Task Leader/Backup</strong> Hosseini/Sun</td>
<td><strong>Task Leader/Backup</strong> Hosseini/Sun</td>
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<td><strong>Task 1 Team</strong> Nicot/Hosseini/Young/Hovorka</td>
<td>Task 2 Team Subtask 2.1 Hosseini/Sun/Postdoc/s Subtask 2.2 Hosseini/Sun/C12 Energy Subtask 2.3 Sun/Hosseini Subtask 2.4 Sun/Hosseini</td>
<td>Task 3 Team Subtask 3.1 Hosseini/Sun/Postdoc/s Subtask 3.2 Hosseini/Sun/Postdoc/s Subtask 3.3 Sun/Hosseini Subtask 3.4 Hosseini/Sun Subtask 3.5 Sun/Hosseini Subtask 3.6 Sun/Hosseini</td>
<td>Task 4 Team Subtask 4.1 Hosseini/Sun/Postdoc/s Subtask 4.2 Sun/Hosseini Subtask 4.3 Sun/Hosseini Subtask 4.4 Sun/Hosseini</td>
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Bibliography

– Journals

– Conferences