Pressure management and geomechanical behavior at industrial partner projects

Joshua White & Thomas Buscheck

Project Number:
FWP-FEW0191-Task 4

Lawrence Livermore National Laboratory
Program Goal No. 4

- Develop Best Practice Manuals for monitoring, verification, accounting, and assessment; site screening, selection and initial characterization; public outreach; well management activities; and risk analysis and simulation.

Benefit Statement

- An understanding of hydro-mechanical interactions is essential for effective monitoring and management of reservoir performance.

- This project seeks to develop:
  - An open source toolkit to support dynamic well-test analysis using multi-rate / multi-well gauge data
  - Active pressure management strategies using pre-production and co-production of brine
Performance Period
May 2016 to April 2019

FY16-17 Task Status

① Statoil data transfer & pre-processing
   Complete

② Active pressure management study
   25%

③ Pressure toolkit development
   25%

Team

- Joshua White -- geomechanics and reservoir engineering
- Thomas Buscheck -- hydrogeology and reservoir engineering
The Snøhvit CO$_2$ Storage Project

[Spencer et al. 2008; Chiaramonte et al. 2014]
Snøhvit CO₂ Storage Project

Figure: N-S vertical cross section through stratigraphy

- **2008 to 2011**: ~1 Mtpa injection into Tubåen Formation
- **2011**: Well re-completion
- **2011 to present**: ~1 Mtpa into Stø Formation
Getting CO$_2$ into the Tubåen Fm. was harder than expected.
Depositional environment controls pressure behavior

- CO$_2$ and pressure confined to narrow sand channels, with limited connectivity between channels

4D difference amplitude map, 2003-2009, lower perforation.

(Hansen et al. 2012)
Snøhvit experience highlights questions faced by all carbon storage projects:

① How can operators identify (and understand) reservoir properties and structure as quickly as possible?

② What mix of monitoring and characterization techniques provides the best information while still being cost effective?

③ How can operators forecast reservoir behavior to make informed and timely decisions?

④ What engineering solutions are available to maximize storage and manage integrity risks?
Part 1. Active Reservoir Pressure Management
Active Reservoir Pressure Management

(a) Well 2
Deep monitoring well
Upper Caprock
Upper reservoir
Lower Caprock
Storage reservoir

(b) Well 3
Deep monitoring well
Well 2
Brine production well
Upper Caprock
Upper reservoir
Lower Caprock
Storage reservoir
Well 1
CO₂ injection well
Shallow monitoring well
Tubåen brine pre-production case study
We have published an EES paper on Tubåen injection. We are working on a similar analysis of the Stø injection.

Managing geologic CO$_2$ storage with pre-injection brine production: a strategy evaluated with a model of CO$_2$ injection at Snøhvit

Thomas A. Buscheck,*a Joshua A. White,a Susan A. Carroll,a Jeffrey M. Bielickib and Roger D. Ainesa
Part 2. Pressure Analysis Toolkit
Complementary techniques are required to adequately monitor and understand subsurface behavior.
Pressure measurements can provide “3D” data. They are just challenging to interpret.

- Falloff testing (and other welltests) commonly used to probe reservoir properties and structure away from the well.
Statoil falloff analysis shows clear indications of flow barriers

- Welltest model suggests flow barriers at 110, 110, and 3000m

**Figure:** Falloff analyses using permanent gauge (2009) and PLT data (2011).
Falloff testing has proven value, but requires shutting in the well for significant periods

Motivating question: Could we derive the same information from ongoing injection data, without shutting in for long periods?
Generalized superposition welltest method

- We use a superposition principle to transform a multi-rate injection into an equivalent single-rate test.

- Equivalent buildup/falloff curve can then be analyzed using standard welltest methods

\[
p(t) = q \times p_C(t)
\]

**Single rate:**

\[
p(t) = \left( \sum_{i=1}^{n} q_{i+1} - q_i \right) \times p_C(t - t_i)
\]

**Multi-rate:**
Generalized superposition welltest method

If there are $M$ pressure data points, these equations can be written as a $M \times N$ linear system,

$$A \vec{x} = \vec{p} \quad \text{with} \quad A_{ij} = \sum_{n=0}^{n<i} (q_{n+1} - q_n) H_j(t_i - t_n)$$
Automatic calibration to Snøhvit data (~5 seconds)
Tool can potentially be used in two modes:

① Reservoir characterization mode

  - Calibrate to gauge data, extract equivalent falloff test
  - Apply standard welltest analysis techniques to results

② Pressure forecasting mode

  - Calibrate to gauge data, project forward in time
  - Quickly explore alternative injection scenarios
Fast-running pressure forecasting

- measurement
- forecast / precast
- calibration period

Equivalent buildup test

Pressure, bar vs. time, days

0 100 200 300 400 500 600 700 800 900 1000 1100
Fast-running pressure forecasting
Fast-running pressure forecasting

![Graph showing pressure over time with different periods highlighted: measurement, forecast/precast, calibration period.](attachment:graph.png)

**Measurement**

**Forecast/Precast**

**Calibration Period**

**Equivalent Buildup Test**
Fast-running pressure forecasting

![Graph showing pressure, bar over time, days with measurement, forecast/precast, and calibration period phases highlighted.](image-url)
Fast-running pressure forecasting

![Graph showing pressure over time with measurement, forecast/precast, and calibration period.]
Fast-running pressure forecasting

Graph showing pressure over time with different segments for measurement, forecast/precast, and calibration period.

Inset graph showing equivalent buildup test.
Accomplishments to date

We have demonstrated the utility of several techniques

① Pre-production of brine as an alternative to co-production in an active pressure management scheme.

② Dynamic welltest analysis, in which ongoing injection data is used to probe reservoir properties without shutting in the well.
Future plans

① Implementing pressure analysis algorithms in an open-source toolkit, freely available to interested parties.
   - Also including multi-well analyses, to look at pressure & poroelastic interactions between wells.

② Testing the effectiveness of pressure management in “open” reservoirs where fluid recharge may impact drawdown effectiveness.
Synergistic Opportunities

We are always looking for opportunities to partner with industrial operations.

Goal is always to provide a two-way benefit:

① We validate our tools on real field data, and ensure they are relevant for high-priority operational decisions.

② We provide back novel analyses and insights useful for an operator.
Acknowledgements

- This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Funding was provided by the DOE Office of Fossil Energy, Carbon Sequestration Program and by Statoil SA.

Contact

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Appendix: Program Management
## Project Timeline for FEW0191

<table>
<thead>
<tr>
<th>Task</th>
<th>Milestone Description*</th>
<th>Project Duration</th>
<th>Start : Oct 1, 2014</th>
<th>End: Sept 30, 2017</th>
<th>Planned Start Date</th>
<th>Planned End Date</th>
<th>Actual Start Date</th>
<th>Actual End Date</th>
<th>Comment (notes, explanation of deviation from plan)</th>
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<td>1.1</td>
<td>Calibrate Reactive Transport Model</td>
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<td>1.2</td>
<td>Calibrate NMR Permeability Estimates</td>
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<td>Scale Reactive Transport Simulations from the core to reservoir scale</td>
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<td>1.4</td>
<td>Write topical report on CO2 storage potential in carbonate rocks</td>
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<td>2.1</td>
<td>Algorithm development and testing</td>
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<td>Array design and monitoring recommendations</td>
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<td>Analysis of monitoring and characterization data available from the In Salah Carbon Sequestration Project</td>
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<td>Wellbore model development</td>
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<td>Analysis of the full-scale wellbore integrity experiments</td>
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<td>Refining simulation tools for sharing with industrial partners</td>
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<td>Develop work scope with industrial partners</td>
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* No fewer than two (2) milestones shall be identified per calendar year per task
Bibliography
