Pressure Analysis Toolkit

Joshua White

Project Number:
FWP-FEW0191-Task 4
LLNL-Equinor CRADA TC002228.001

Lawrence Livermore National Laboratory
Fundamental question: How to design a monitoring program to adequately balance effectiveness vs. cost?
**Fundamental question:** How to design a monitoring program to adequately balance effectiveness vs. cost?
Project Objective

Develop an open-source software toolkit to support the development and deployment of new techniques for analyzing well gauge data.
Project Timeline
May 2016 to April 2019

Deliverable Status

- **April 2017**: Cypress version 0.8 (pre-release) delivered for testing to Equinor
- **April 2018**: Cypress version 0.9 (pre-release) delivered for testing to Equinor
- **April 2019**: Cypress version 1.0 open-source release planned (LGPL license)
Major Features

- Data visualization and manipulation
- Bottomhole pressure estimation algorithms
- Deconvolution welltest algorithms
- Rapid pressure forecasting
- Type-curve analysis support
- Fracture-pressure identification algorithms
Step 1: Import gauge data
Step 2: Choose / Import a CO₂ PVT Table
Step 3: Bottomhole Pressure Estimation

Estimation Method

Methods:
1) Single-Gauge
2) Two-Gauge
3) Multi-Gauge

Input Data

Two-Gauge Method
Select datasets and options

- PVT table: PVTSim > Density (kg/m^3)
- Temperature gauge 1: Stø > xmas temperature (°C)
- Temperature gauge 2: Stø > gauge temperature (°C)
- Pressure gauge: Stø > gauge pressure (bar)
- Flow rate: Stø > injection rate (Sm3/d)
- Extrapolate to depth: 2583
- Friction loss: Friction factor
- Name for results: BHP @ 2583m

< Back  Compute BHP
BHP Estimation: Tubåen Test

Test: Use wellhead data to estimate known gauge data

1. Span-Wagner EOS (High)
2. Measured Data
3. PVTSim EOS (Low)
Falloff testing (and other welltests) are commonly used to probe reservoir properties and structure away from the well.
Traditional welltest techniques require shutting in the well for significant periods.

Key question: Is the same information from ongoing injection data, without shutting in for long periods?
Deconvolution Welltest Analysis

**Basic Idea:** Given $p(t)$ and $q(t)$, estimate $g(t)$ through a deconvolution method.

Convolution Integral:

$$\Delta p(t) = \int_0^\tau q(\tau) g(t - \tau) d\tau$$

- Reservoir Impulse Response (Unknown)
- Reservoir Pressure Change (Measured)
- Injection Rate (Measured)

Deconvolution results can then be readily converted to a traditional diagnostic plot format

**Buildup (or Falloff) Response:**

\[ P_u(t) = \int_0^t g(t) \, dt \]

**Logarithmic Derivative:**

\[ \frac{dP_u}{d \ln t} = tg(t) \]
Deconvolution Analysis: Tubåen Data
Deconvolution Analysis: Tubåen Data
Deconvolution Analysis: Tubåen Data
Deconvolution Analysis: Tubåen Data

- measurement
- forecast / precast
- calibration period

Pressure (bar) vs. time (days) graph showing data trends over a period.
Deconvolution Analysis: Tubåen Data
Deconvolution Analysis: Tubåen Data
Stø Injection

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
Recent Work: Multi-well Interference

- When multiple wells interfere with one another, data deconvolution can be performed simultaneously on all wells to extract build-up response functions ($G$).

\[
P_1 = G_1(Q_1) + G_{12}(Q_2)
\]

\[
P_2 = G_2(Q_2) + G_{12}(Q_1)
\]
Multi-well Interference: Stør Dataset

Deconvolution Model

Measured Data
Looking forward, our goal is to provide a research platform to help answer the following questions:

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?
Synergistic Opportunities

We welcome new ideas for pressure analysis algorithms that might be included in the toolkit.

We are also happy to partner with operators to further validate the proposed methods on real field cases.
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 Equinor SA.

Contact

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Appendix: Program Management
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 well gauge data
  - Best practices for using gauge data to cost-effectively monitor reservoir performance
Org Chart

Fuel Cycles Innovations (Roger Aines)

Carbon Management (Susan Carroll)

LLNL Carbon Sequestration Program

Task 1. Carbonates

Task 2. Induced Seismicity

Task 3. Caprock & Well Integrity

Task 4. Industrial Partnerships

Technical Staff

Carroll, Hao, Smith

Matzel, Templeton, White

Carroll, Hao, Iyer, Morris, Roy, Walsh, Wang, White

Carroll, White

Expertise

Subsurface Hydrology

Computational Geomechanics

Experimental and Theoretical Geochemistry

Seismology
## 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>
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<td>1.1</td>
<td>Calibrate Reactive Transport Model</td>
<td><strong>Project Year (PY)</strong> 1</td>
<td>Q1</td>
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* No fewer than two (2) milestones shall be identified per calendar year per task.
Bibliography

The Snøhvit CO$_2$ Storage Project

[Spencer et al. 2008; Chiaramonte et al. 2014]
Depositional environment controls pressure behavior

- $\text{CO}_2$ and pressure confined to narrow sand channels, with limited connectivity between channels.
Statoil fall-off 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).