DOE Award No.: ESD12010

Quarterly Research Performance Progress Report
(Period Ending 6/30/2018)

NUMERICAL STUDIES FOR THE CHARACTERIZATION OF RECOVERABLE RESOURCES FROM METHANE HYDRATE DEPOSITS
Project Period (April 1, 2012 to December 31, 2018)

Submitted by:
Matthew T. Reagan

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Signature

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Prepared for:
United States Department of Energy
National Energy Technology Laboratory

June 30, 2018
ACCOMPLISHMENTS:

Task 1. Project Management Plan

Status: Ongoing

A PMP was submitted for Budget Period #6 in March 2017. A revised FWP and SOPO was submitted on July 31, 2017. A revised for the new, extended BP #6 was submitted in August, 2017.

Task 2. Code Maintenance, Updates, and Support

Subtask 2.6:

Status: Ongoing, task expanded 7/31/2017

Development of the new Millstone geomechanical code has been ongoing, and has now been tested in real-world simulation problems associated with other tasks in the FWP, including new capabilities for static post-processing of pre-existing T+H simulation.

The release of the new coupled T+H/Millstone platform was accompanied by the submission of three papers that document 1) T+H code development, 2) Millstone code development, and 3) testing of the latest coupled simulator. These papers are still in review for *Transport in Porous Media* due to difficulties finding qualified reviewers capable of evaluating the coupled T+H+M simulation process.
Task 3. Support of DOE’s Field Activities and Collaborations

Subtask 3.6: Detailed Analysis of the Production Potential of Hydrates Deposits Offshore India

Status: Ongoing

The latest versions of the T+H and Millstone codes, developed in Task 2, were used for ongoing simulations of the India NGHP Site 9 production test. In this quarter, the team completed analysis of all the simulations of production scenarios, with and without coupled geomechanics, using data and geological models developed in consultation with NETL, USGS, and Indian scientists. The final simulations ended in June 2018. Problems caused by purely technical issues were overcome, and recent delays were solely the result of the extremely long execution times required to properly model the system, with multi-million-timestep simulations consuming close to 1 million CPU-hours.

The reason for these very short time steps continued to be the extreme variation in permeability between the hydrate-bearing layers (~1.0 mD or less) and the hydrate-free sand (~10.0D). The 4-order difference in permeability causes a multitude of problems: the very fine radial discretization along the hydrate-free sand lenses result in practically zero pressure differences between adjacent grid elements, making the computation of gradients and derivatives both difficult and inaccurate for the Jacobian needs of the fully implicit model in TOUGH+HYDRATE.

The results from these simulations were submitted to the journal special issue associated with the India NGHP in late April 2018 and the results were presented in a confidential report to the NGHP leadership in April. The paper has undergone one round of review and is currently under revision:


Subtask 3.7: Participation in the Code Comparison Study of Coupled Flow, Thermal and Geomechanical Processes

Status: Ongoing

The LBNL team has been participating in the regular meetings and has contributed problem solutions. Matt Reagan and Alejandro Queiruga are designing Problem #3, a variation of a standard axisymmetric coupled flow-mechanical test problem, which will be submitted to the study in August 2018.

As part of this code comparison study, we have also begun an investigation into mesh convergence for our Darcy simulator with and without hydrate in the system. During review of several recent papers, questions were raised about the choice of discretization, particularly near the well. Currently, these values are chosen by experience or by trial and error, and often
decisions are made to limit mesh sizes at the expense of mesh refinement. No formal assessment of this exists. As part of Problem #3, we are performing mesh convergence testing with and without hydrate to assess whether mesh generation is being done correctly, with results expected in Q4.

**Task 4. Assessment of Resource Recoverability From Natural Hydrate Deposits**

**Subtask 4.4:**

**Status: Completed**

Work on Subtask 4.4 concluded in Q3, with the work focusing on simulations of the production behavior of horizontal wells in sloping systems and the geomechanical consequences. Current funding was exhausted at the end of June 2018.

**Milestone Table**

<table>
<thead>
<tr>
<th>Milestone Title</th>
<th>Milestone Description</th>
<th>Planned Completion Date</th>
<th>Actual Completion Date</th>
<th>Status / Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMP</td>
<td>Maintenance and update of the Project Management Plan</td>
<td>April 30, 2016, March 30, 2017</td>
<td>Included with BP#6 SOPO 3/15/17</td>
<td>Updated 30 days after receipt of added BP #6 funding</td>
</tr>
<tr>
<td>Deliverable</td>
<td>Report and presentation(s) regarding the results of the initial Subtask 3.6 simulations</td>
<td>June 30, 2017</td>
<td>Results to date presented at ICGH 9 on June 26-30, 2017</td>
<td>Subtask 3.6 extended and expanded to cover a wider range of scenarios and parameters through July 2018,</td>
</tr>
<tr>
<td>Deliverable</td>
<td>Completed T+H/ROCMech Code Updates</td>
<td>December 31, 2016</td>
<td>March 27, 2018**</td>
<td>ROCMECH found to be incompatible with cylindrical well simulations (i.e., India NGHP studies). Development suspended in May 2016 with the beginning of Millstone development. **T+H/Millstone v1.0 completed in March 2018.</td>
</tr>
<tr>
<td>Deliverable</td>
<td>Submission of a paper on the expected long-term fate and transport of released gas following the cessation of operations</td>
<td>July 31, 2016</td>
<td>December 12, 2016, June 30, 2017</td>
<td>Results presented as a poster at AGU Fall Meeting. Paper submitted to ICGH 2017 and presented June 30, 2017.</td>
</tr>
<tr>
<td>Deliverable</td>
<td>A paper (jointly with T. Kneafsey) on the design and analysis of the planned experiments.</td>
<td>May 31, 2017</td>
<td>Pending</td>
<td>Delays in experiments have resulted in a delay in producing a paper. We are currently evaluating completed tests.</td>
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<tr>
<td>Deliverable</td>
<td>Updated versions serial and parallel versions of the T+M/Millstone code</td>
<td>July 31, 2018</td>
<td>March 27, 2018</td>
<td>Three papers describing T+H/Millstone submitted to Transport in Porous Media.</td>
</tr>
<tr>
<td>Deliverable</td>
<td>Completion of analyses and participation in the code comparison study</td>
<td>July 31, 2018</td>
<td>Ongoing</td>
<td>Problem #1 completed in Q2. Problem #2 and #3 to be completed in early Q3. CCS expected to continue into FY19.</td>
</tr>
<tr>
<td>Deliverable</td>
<td>Submission of a report on the ongoing studies of offshore Indian hydrates</td>
<td>Jul 31, 2018</td>
<td>April 13, 2018</td>
<td>Report submitted to NGHP; Report condensed into paper submitted to JMPG.</td>
</tr>
<tr>
<td>Deliverable</td>
<td>Submission of a report on the evolution of subsidence and strategies to mitigate production problems</td>
<td>Jul 31, 2018</td>
<td>Ongoing</td>
<td>Work ongoing</td>
</tr>
</tbody>
</table>

**PRODUCTS:**

**Publications to date (this BP):**


Moridis, G.J., Reagan, M.T., Queiruga, A.F., Collett, T.S., Boswell, R., Evaluation of the Performance of the Oceanic Hydrate Accumulation at the NGHP-02-9 Site of the Krishna-
Godawari Basin During a Production Test and Under Full Production, submitted to *J. Marine and Petroleum Geology*.

**Presentations to date (this BP):**

“Long-Term System Behavior Following Cessation of Gas Production from Hydrate Deposits,” 9th Int. Conference on Gas Hydrates, Denver, CO, 1-3 June 2017.


“Current Advances in Laboratory and Simulation Studies at LBNL,” National University of Singapore, 27 March 2018.

**SPECIAL REPORTING REQUIREMENTS:**

N/A

**BUDGETARY INFORMATION:**

<table>
<thead>
<tr>
<th>Actual Cost (this quarter)</th>
<th>Actual Cost (cumulative for BP)</th>
<th>Funds available (for the BP)</th>
<th>Balance of unspent funds (for the BP)</th>
<th>Actual Cost (cumulative for the full FWP)</th>
<th>Funds available (for the full FWP)</th>
<th>Balance of unspent funds (for the full FWP)</th>
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