NATIONAL ENERGY TECHNOLOGY LABORATORY
OIL & GAS

DOE Award No.: ESD12010

Quarterly Research Performance Progress Report

(Period Ending 09/30/2017)

NUMERICAL STUDIES FOR THE CHARACTERIZATION OF RECOVERABLE RESOURCES FROM METHANE HYDRATE DEPOSITS

Project Period (April 1, 2012 to open)

Submitted by:
Matthew T. Reagan

Matthew T. Reagan

Signature

Lawrence Berkeley National Laboratory
DUNS #:xxxxxxx
1 Cyclotron Road
Berkeley CA 94720
Email: mtreagan@lbl.gov
Phone number: (510) 486-6517

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

October 31, 2017

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Office of Fossil Energy

RESEARCH PERFORMANCE PROGRESS REPORT

DISCLAIMER

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

Developed of the new STONE geomechanical code has been ongoing.

The updated T+H and STONE (T+M) codes are being used for ongoing simulations of the India NGHP Site 9 production test. Additional capabilities will be developed in the proposed work scheduled in the expanded BP #6.

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 version of the T+H and STONE codes, developed in Task 2 are being used for ongoing simulations of the India NGHP Site 9 production test. In this quarter, the team completed simulations of several Site 9 production scenarios, with and without coupled geomechanics, and also examined the fate of hydrate reservoirs after the cessation of production (using the Site 9 reference case anonymously). Two conference papers and two presentations resulted from this work.

More recently, using data and geological models developed in consultation with NETL, USGS, and Indian scientists, we used the latest Meshmaker 2.0 software to generate new/updated meshes for continuing simulations of the Site 9 case and sensitivity studies. These new simulations started in July 2017 and have been in progress for several months now. However, there have been delays caused by purely technical issues. The first issue was the determination of the appropriate space discretization: given the new geologic model for Site 9 and its associated extensive layering, we ran several scoping (preliminary) calculations to determine the upper limit of the space discretization (i.e., the grid, further refinement of which brought no change in the simulation results). This is a very important issue in hydrate simulation because inappropriate space discretization can easily distort (significantly) the model predictions. We finally determined the appropriate grid, which involves about 240K elements and thus about 1 million equations. Additionally, we had to agree collectively (in a series of telephone conferences with my DOE/NETL and USGS colleagues) on the properties of Site 9, which is less well-described than Site 16. A connectivity-based rendering of the grid is shown below in Figures 1 and 2.

The other technical issue that has been hampering us is supercomputer availability: although LBNL is the site of National Energy Supercomputer Center (NERSC), access to supercomputer facilities has been a problem because (a) they are heavily used by researchers from all over the world, (b) allotments are limited for projects not funded through the Office of Science, and (c) the optimum number of processors we need for 1 M equations (about 300-500) puts us in a low-priority queue (NERSC computers assign high priority to submissions with at least 10,000 processors). We have overcome the problem by using a new pay-per-use supercomputer system that provides us easy access, but the number of processors we can use is subject to user load.

The extreme non-linearity of the Site 9 problem is currently resulting in a very large number of time steps (hundreds of thousands to millions). During the early stages of production (5 days or so), time steps as short as 0.1 to 0.2 sec are the norm, leading to very long execution times that are compounded by the difficulty of access to supercomputers. The reason for these very short time steps is 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. Additionally, the high flow rate along the hydrate-free lenses caused very steep salt concentration and temperature gradients between them and the adjacent hydrate-bearing layers. These conditions that are particular to

Site 9 drastically aggravate an already difficult (i.e., strongly non-linear) problem of coupled flow, thermal and geomechanical processes, and lead to the very long execution times that we are experiencing.

Simulations will continue through the following quarter, with expected completion of the analysis and all sensitivity variations in January 2018.

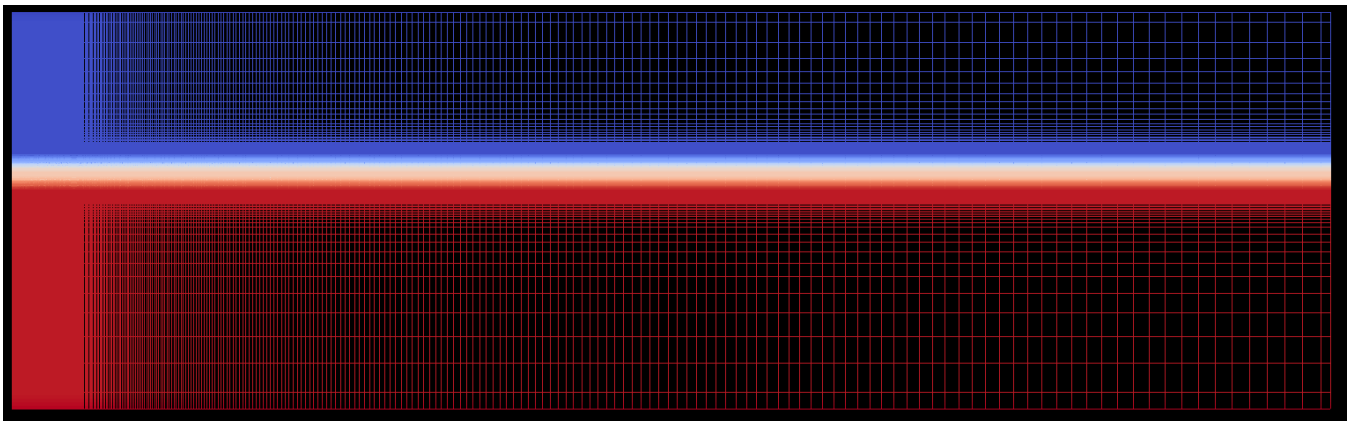

Figure 1: Radial Site 9 mesh, color-coded by layer/rock type.

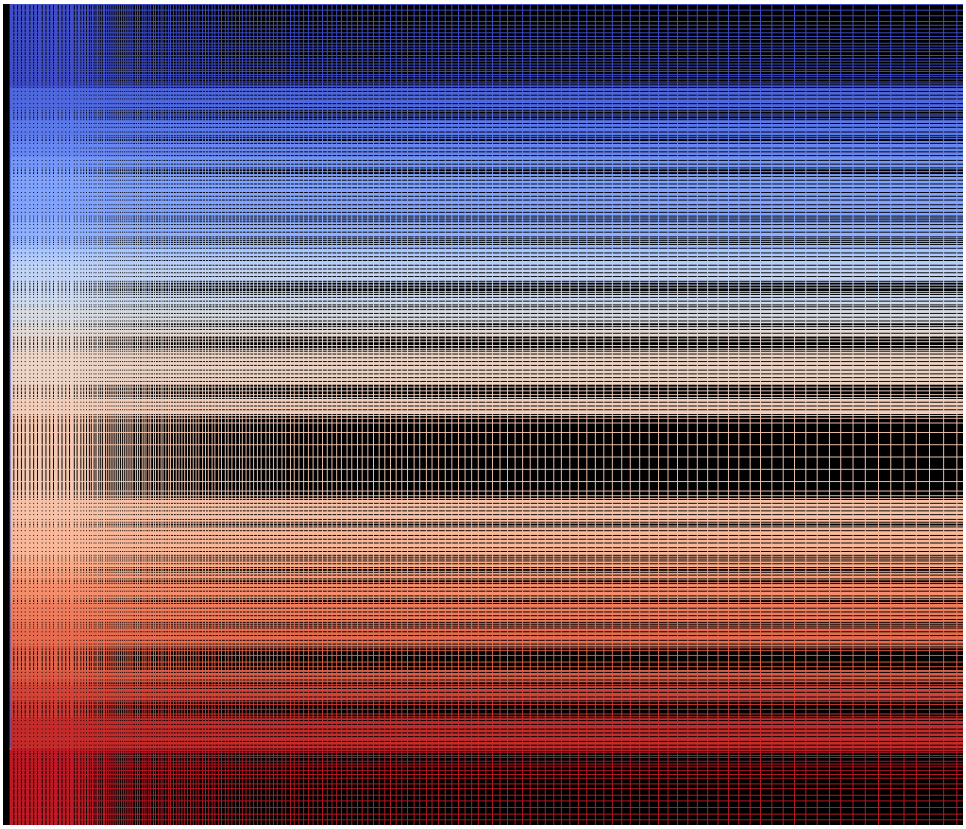

Figure 2: Radial Site 9 mesh, showing near-well zone with hydrate, mud, and aquifer layers with varying discretization.

Earlier work on the Site 9 has been compiled into three publications to be submitted in November, 2017:

Moridis, G.J., Reagan, M.T., Queiruga, A.F., The T+H+M Code for the Analysis of Coupled Flow, Thermal, Chemical and Geomechanical Processes in Hydrate-Bearing Geologic Media, Part I: The Hydrate Simulator. *Submitted to Computers and Geosciences.*

Queiruga, A.F., Moridis, G.J., Reagan, M.T., The T+H+M Code for the Analysis of Coupled Flow, Thermal, Chemical and Geomechanical Processes in Hydrate-Bearing Geologic Media, Part I: Numerical Algorithms and the Stone Geomechanical Simulator. *Submitted to Computers and Geosciences.*

Reagan, M.T., Queiruga, A.F., Moridis, G.J., The T+H+M Code for the Analysis of Coupled Flow, Thermal, Chemical and Geomechanical Processes in Hydrate-Bearing Geologic Media, Part III: Application to a Reservoir Simulation Problem. *Submitted to Computers and Geosciences.*

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

Status: Beginning 10/2017

The LBNL team is ready to participate, and will attend the first group meeting on November 9.

Task 4. Assessment of Resource Recoverability From Natural Hydrate Deposits

Subtask 4.4:

Status: Beginning 10/2017

Milestone Table

Milestone Title	Milestone Description	Planned Completion Date	Actual Completion Date	Status / Results
PMP	Maintenance and update of the Project Management Plan	April 30, 2016	Included with BP#6 SOPO 3/15/17	Will be updated 30 days after receipt of added BP #6 funding
Topical Report/Presentation	Report and presentation(s) regarding the results of the initial Subtask 3.6 simulations	June 30, 2017	Results to date presented at ICGH 9 on June 26-30, 2017.	Subtask 3.6 extended and expanded to cover a wider range of scenarios and parameters through July 2018,

PRODUCTS:

Publications:

Reagan, M.T., Moridis, G.J., Seim, K.S., "Fast Parametric Relationships for the Large-Scale Reservoir Simulation of Mixed CH4-CO2 Gas Hydrate Systems," *Computers and Geosciences*, **103**, 191-203, 2017.

Moridis, G.J., Reagan, M.T., Queiruga, A.F., "Long-Term System Behavior Following Cessation of Gas Production from Hydrate Deposits," *Proc.* 9th Int. Conference on Gas Hydrates, Denver, CO, 1-3 June 2017.

Moridis, G.J., Queiruga, A.F., Reagan, M.T., "The T+H+M Code for the Analysis of Coupled Flow, Thermal, Chemical and Geomechanical Processes in Hydrate-Bearing Geologic Media," *Proc.* 9th Int. Conference on Gas Hydrates, Denver, CO, 1-3 June 2017.

Presentations:

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

"The T+H+M Code for the Analysis of Coupled Flow, Thermal, Chemical and Geomechanical Processes in Hydrate-Bearing Geologic Media," 9th Int. Conference on Gas Hydrates, Denver, CO, 1-3 June 2017.

CHANGES/PROBLEMS:

An updated SOPO for Budget Period #6 was submitted to NETL on July 31, 2017. This new SOPO extends Task 2.6 and Task 3.6, and also adds a new Task 3.7 to the project. A new PMP, reflecting the new tasks and extended timelines, was submitted in August 2017.

SPECIAL REPORTING REQUIREMENTS:

N/A

BUDGETARY INFORMATION:

Actual Cost (this quarter)	Actual Cost (cumulative for BP)	Funds available (for the BP)	Balance of unspent funds (for the BP)	Actual Cost (cumulative for the full FWP)	Funds available (for the full FWP)	Balance of unspent funds (for the full FWP)
$85,618	$200,326	$350,000*	$219,784**	$1,100,326	$1,250,000*	$219,784**

* this includes the additional $150,000 to be added to the FWP for BP #6.
** this includes overlapping funds/carryover between BP #5 and BP#6.

National Energy Technology Laboratory

626 Cochrans Mill Road

P.O. Box 10940

Pittsburgh, PA 15236-0940

3610 Collins Ferry Road

P.O. Box 880

Morgantown, WV 26507-0880

1450 Queen Avenue SW
Albany, OR 97321-2198

Arctic Energy Office

420 L Street, Suite 305

Anchorage, AK 99501

Visit the NETL website at:

www.netl.doe.gov

Customer Service Line:

1-800-553-7681