NATIONAL ENERGY TECHNOLOGY LABORATORY
OIL & GAS

DOE Award No.: ESD12010

Quarterly Research Performance Progress Report

(Period Ending 12/31/2017)

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

Project Period (April 1, 2012 to open)

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

January 31, 2018

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 code has been upgraded to a full 3D formulation (in addition to the 2.5D cylindrical formulation reported earlier) an full testing and validation is an ongoing process. In addition, a new capability has been added: static post-processing of pre-existing T+H simulation results to retroactively assess geomechanical evolution of the system (although not in a fully-coupled form).

The updated T+H and STONE codes (now labeled TS_H in coupled form) 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 additional Site 9 production scenarios, with and without coupled geomechanics, 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, based on updated data, have been in progress for several months now. Delays caused by purely technical issues, reported in the last quarter, were overcome (space discretization and grid refinement).

One technical issue that continues to slow us down us is supercomputer availability. Although LBNL is the site of National Energy Supercomputer Center (NERSC), access to supercomputer facilities has been a problem because allotments are limited for projects not funded through the Office of Science. We continue to use a pay-per-use supercomputer system (Lawrencium) that provides us easy access, but the number of processors we can use is subject to user load. Also, the cost of this system (which can be several thousand dollars a month at peak use), is billed out of project funds.

The extreme non-linearity of the Site 9 problem resulted 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 were the norm, leading to very long execution times, even using the 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. 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. Additional scenarios involved multiple wells at varying spacing have shown greatly improved numerical behavior, as they result in more dramatic depressurization of the system and reduced water inflow.

As of December 31, five new cases have been simulated:

1) New reference case, involving a single vertical well, using the new layered system and updated reservoir properties
2) New case with the permeable interlayer excluded from the perforated interval of the well
3) New closed case, simulating a pattern of wells at 2000 m spacing (r = 1000 m)
4) New closed case, simulating a pattern of wells at 200 m spacing (r = 100 m)

5) New closed case, simulating a pattern of wells at 150 m spacing (r = 75 m)

Cases 4 and 5 have been completed to 540 days (the duration of the field test). Case 2 has been stopped after 50 days of production after initial analysis indicated that the results were essential identical to the new reference case after a few days of production. Case 3 is currently running, having consumed over 100,000 processor-hours of cluster time, and is expected to be the most challenging of the five cases to simulate due to the unique combination of high water production at early times and slow transition to strong depressurization after five months of production (trends in hydrate dissociation and production rate, however, suggest that productivity will increase after 200 days). Case 1, the reference case, was suspended at t = 200 d after results indicated that high water flows from the boundaries via the interlayer, aquifer, and through open pathways through the hydrate layers were preventing effective depressurization of the system and thus production rates that fail to increase with time.

The results from these simulations will be fully analyzed in Q2, and presented in a paper to be submitted to the journal special issue associated with the India NGHP. The results will also be presented in a confidential report to the NGHP leadership.

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 presented our capabilities on December 7.

Task 4. Assessment of Resource Recoverability From Natural Hydrate Deposits

Subtask 4.4:

Status: Ongoing

Work on Subtask 4.4 began in November 2017. The work focused on the generation of meshes for the sloping systems described in the FWP and preliminary simulations of the production behavior of horizontal wells in sloping systems. The geomechanical consequences of production and post-production re-equilibration were assessed for each case, and results suggested there is little or no chance of slope failure during the production cycle.

A paper (confidential and not for distribution), “Geomechanical Stability and Overall System Behavior of Sloping Oceanic Accumulations of Hydrates Responding to Dissociation Stimuli,” is attached, documenting the work done to date.

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 to date (this BP):

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.

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

Moridis, G.M., Reagan, M.T., Queiruga, A.F., Geomechanical Stability and Overall System Behavior of Sloping Oceanic Accumulations of Hydrates Responding to Dissociation Stimuli, OTC-24896-MS,*Proc.* Offshore Technology Conference-Asia, 20 March 2018.

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.

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)
$90,956	$291,282	$350,000*	$128,829**	$1,121,171	$1,250,000*	$128,829**

* 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.

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