

DOE Award No.: FP00008138

Quarterly Research Performance Progress Report

(Period Ending 3/31/2019)

**NUMERICAL STUDIES FOR THE CHARACTERIZATION OF
RECOVERABLE RESOURCES FROM METHANE HYDRATE DEPOSITS**
Project Period (August 1, 2018 to Open)

Submitted by:
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U.S. DEPARTMENT OF
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**NATIONAL ENERGY
TECHNOLOGY LABORATORY**

Office of Fossil Energy

RESEARCH PERFORMANCE PROGRESS REPORT

DISCLAIMER

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ACCOMPLISHMENTS:

Task 1. Project Management Plan

Status: Ongoing

A Draft PMP was submitted for Budget Period #1 in July 2018, with a revised FWP and SOPO.

Task 2. Code Maintenance, Updates, and Support

Status: Ongoing

The three-part paper series documenting the TOUGH+HYDRATE/Millstone suite went into publication at the end of March 2019 (issue numbers TBD):

Moridis, G.J., Reagan, M.T., Queiruga, A.F., “Simulation of Gas Production from Multilayered Hydrate-Bearing Media with Fully Coupled Flow, Thermal, Chemical and Geomechanical Processes Using TOUGH+Millstone, Part I: The Hydrate Simulator,” *Transport in Porous Media*, **in press**, doi: 10.1007/s11242-019-01254-6.

Queiruga, A.F., Moridis, G.J., Reagan, M.T., “Simulation of Gas Production from Multilayered Hydrate-Bearing Media with Fully Coupled Flow, Thermal, Chemical and Geomechanical Processes Using TOUGH+Millstone, Part II: Geomechanical Formulation and Numerical Coupling” *Transport in Porous Media*, **128**(1), 221-241, doi: 10.1007/s11242-019-01242-w.

Reagan, M.T., Queiruga, A.F., Moridis, G.J., “Simulation of Gas Production from Multilayered Hydrate-Bearing Media with Fully Coupled Flow, Thermal, Chemical and Geomechanical Processes Using TOUGH+Millstone, Part III: Application to Production Simulation,” *Transport in Porous Media*, **in press**, doi: 10.1007/s11242-019-01283-1.

An invited talk concerning the TOUGH+/Millstone coupling was presented in Q2:

Queiruga, A. F., “Fully Coupled Multimesh Algorithms for Nonisothermal Multiphase Flow and Mechanics in Geological Formations,” **(invited)** SIAM Conference on Mathematical & Computational Issues in Geosciences, Houston, Texas, March 2019.

Task 3. Support of DOE’s Field Activities and Collaborations

Subtask 3.1: Design support for a DOE-led field test in the North Slope of Alaska
Status: Pending

We have not begun discussions about the upcoming field test.

Subtask 3.2: Activities in support of DOE international gas hydrate collaborations
Status: Ongoing

Our group finished revisions on the paper for the JMPG Special Edition on the India Gas Hydrates program, and the paper has been accepted and is available online:

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-Godavari Basin During a Production Test and Under Full Production, *J. Marine and Petroleum Geology*, **in press**, doi: 10.1016/j.marpetgeo.2018.12.001.

A paper related to the DOE collaboration with KIGAM was published:

Moridis, G.J., Reagan, M.T., Queiruga, A.F., Kim, S.J., System response to gas production from a heterogeneous hydrate accumulation at the UBGH2-6 site of the Ulleung basin in the Korean East Sea, *J. Pet. Sci. Eng.*, **178**, 655-665. doi: 10.1016/j.petrol.2019.03.058.

Subtask 3.3: Participation in the Code Comparison Study
Status: Ongoing

LBNL contributed solutions to Problems #1, #2, and #4, and designed Problem #3. We participated in regular teleconferences with study leaders and other simulation teams. The insights gained from the CCS have led to the development of a new code testing and validation system for TOUGH+HYDRATE (see Task 2), as well as motivating us to perform additional evaluations of the TOUGH+ code architecture, numerical methods, and other issues.

Task 4. Exploration of High-Efficiency Modeling Methods for Hydrate Reservoir Simulation

Status: Ongoing

Using the lens of machine learning, we have reformulated the problem of multiphase flow and are developing a new algorithm to both implement and program the simulations. We use deep learning techniques to learn new representations of the complex equations of state that can be directly employed inside of a mass-and-energy balance formulation. A new type of simulation prototype has been developed wherein the material properties of a single grid block are represented by a learned model. Basic proofs of concept of the new simulation framework have been demonstrated. An invited presentation on this work was presented:

Queiruga, A.F., "Machine Determination of Better Representations of Multiphase Equation of States for Subsurface Flow Simulation" at Machine Learning in Solid Earth Geosciences, 18-22 March 2019 in Santa Fe, NM.

The presentation slides are available online:

<https://www.ocf.berkeley.edu/~afq/present/SantaFe2019/>

The Python implementation of equations of state for water from literature that was used to assemble the training set are available on GitHub:

https://github.com/afqueiruga/equations_of_state

The prototype codebase is currently in the last stages of validation and debugging, and manuscript preparation has begun. The TensorFlow package was determined to be too slow for usage in a fully-fledged simulation package. New software engineering methods will be needed to incorporate these new types of techniques into existing workflows. Current work involves researching new software packages, dataset management techniques, machine learning task scheduling, compilation, etc. for the next stage of development with the end goal of preparing the newly developed computational techniques for usage in a production simulation package.

Task 5. Publications, Tech Transfer, and Travel

Status: Ongoing

No new submitted publications in the first five months of the Budget Period.

Conference travel to date:

1. Mastering the Subsurface, Carbon Storage and Oil and Natural Gas Conference, Pittsburgh, PA 13-16 August 2018.
2. Machine Learning in Solid Earth Geoscience, Santa Fe, Nevada, March 2019

3. SIAM Conference on Mathematical & Computational Issues in Geosciences, Houston, Texas, March 2019

Milestone Table

Milestone Title	Milestone Description	Planned Completion Date	Actual Completion Date	Status / Results
PMP	Maintenance and update of the Project Management Plan	August 30, 2018	Included with SOPO 7/25/18	Submitted
Deliverable	Updated versions serial and parallel versions of the T+H/Millstone code	May 30, 2019		
Deliverable	Report describing the design and performance of the proposed field test.	August 31, 2019		
Deliverable	Completion participation in the code comparison study; contributions to reports and publications	August 31, 2019		
Deliverable	An assessment of the feasibility, effectiveness and robustness of ROMs	August 31, 2019		

PRODUCTS:

Publications to date (this BP):

- Moridis, G.J., Reagan, M.T., Queiruga, A.F., "Simulation of Gas Production from Multilayered Hydrate-Bearing Media with Fully Coupled Flow, Thermal, Chemical and Geomechanical Processes Using TOUGH+Millstone, Part I: The Hydrate Simulator," *Transport in Porous Media*, in press, doi: 10.1007/s11242-019-01254-6.
- Queiruga, A.F., Moridis, G.J., Reagan, M.T., "Simulation of Gas Production from Multilayered Hydrate-Bearing Media with Fully Coupled Flow, Thermal, Chemical and Geomechanical Processes Using TOUGH+Millstone, Part II: Geomechanical Formulation and Numerical Coupling" *Transport in Porous Media*, **128**(1), 221-241, doi: 10.1007/s11242-019-01242-w.
- Reagan, M.T., Queiruga, A.F., Moridis, G.J., "Simulation of Gas Production from Multilayered Hydrate-Bearing Media with Fully Coupled Flow, Thermal, Chemical and Geomechanical Processes Using TOUGH+Millstone, Part III: Application to Production Simulation," *Transport in Porous Media*, in press, doi: 10.1007/s11242-019-01283-1.
- 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-Godavari Basin During a Production Test and Under Full Production, *J. Marine and Petroleum Geology*, in press, doi: 10.1016/j.marpetgeo.2018.12.001.
- Moridis, G.J., Reagan, M.T., Queiruga, A.F., Kim, S.J., System response to gas production from a heterogeneous hydrate accumulation at the UBGH2-6 site of the Ulleung basin in the Korean East Sea, *J. Pet. Sci. Eng.*, **178**, 655-665. doi: 10.1016/j.petro.2019.03.058.

Presentations to date (this BP):

- “Numerical Studies for the Characterization of Recoverable Resources from Methane Hydrate Deposits,” Mastering the Subsurface, Carbon Storage and Oil and Natural Gas Conference, Pittsburgh, PA 13-16 August 2018.
- “Numerical Studies for the Characterization of Recoverable Resources from Methane Hydrate Deposits,” project wrapup meeting. 28 September 2018.
- “Machine Determination of Better Representations of Multiphase Equation of States for Subsurface Flow Simulation” at Machine Learning in Solid Earth Geosciences, 18-22 March 2019 in Santa Fe, NM.
- “Fully Coupled Multimesh Algorithms for Nonisothermal Multiphase Flow and Mechanics in Geological Formations,” **(invited)** SIAM Conference on Mathematical & Computational Issues in Geosciences, Houston, Texas, March 2019.

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)
\$65,455	\$254,952	\$500,000	\$245,048	\$254,952	\$500,000	\$245,048

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