NATIONAL ENERGY TECHNOLOGY LABORATORY

OIL & GAS

DOE Award No.: FP00008138

Quarterly Research Performance Progress Report (Period Ending 12/31/2019)

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 ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Office of Fossil Energy

RESEARCH PERFORMANCE PROGRESS REPORT

DISCLAIMER

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.

A new postdoc (Dr. Zhi Li, PhD from University of Texas) was hired in Q4 FY19, and in Q1 FY20 he received training on the use of the serial and parallel versions of TOUGH+HYDRATE.

At the end of Q1, Alejandro Quieruga left LBNL on short notice.

Task 2. Code Maintenance, Updates, and Support

Status: Ongoing

An empirical model for the properties of mixtures of liquid water, salt, and gas was found in the literature. The empirical model was implemented in TOUGH+HYDRATE to further improve the accuracy of the density formulations in the current state-of-the-art simulator, and will be included in the next release of the T+M simulator. Also, use of TOUGH+HYDRATE on other non-DOE projects revealed complications in the thermodynamic relationships used to manage hydrate formation in situations where the system is water-limited. While this situation is rare for the systems studied through this

FWP, the HYDRATE EOS has been modified to fix issues with small timesteps during water-limited hydrate formation. These improvements will be included in the next release of the T+M simulator

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: Ongoing

We began discussions about the upcoming field test in Q4, received data in August 2019, and received revised data in December 2019.

Preliminary results for the reference case and several sensitivity cases were presented to the DOE team in October, 2019.

The preliminary results indicated:

1. The system exhibits significant H_2O production and inefficient depressurization (i.e., reduced hydrate dissociation) because of significant/persistent H_2O inflows from the permeable boundaries.
2. If the production strategy of step-wise pressure decline is replaced with a fast linear decline in bottomhole pressures, this yields higher gas production, but also higher H_2O production.
3. The effect of relative permeability parameters is significant in terms of gas and H_2O production, but not so in terms of water-to-gas ratio (still poor). However, this defines the envelope of possible production estimates.
4. Varying the length of the production interval was shown to be inconclusive (up to this point), as production is affected by the considerable S_H variability with depth.

As a general conclusion: water production is a pervasive issue for this system, and production operation management or well construction can have only minor effects on H_2O production.

The preliminary analysis, plus the results of simulations performed in January 2020, will be presented at the 2020 Gordon Conference on Natural Gas Hydrate Systems in Galveston TX on February 23-28, 2020.

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

Our group finished in Q3 the paper for the JMPG Special Edition on the India Gas Hydrates program, and the special issue was released in Q1 FY20.

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 addition evaluations of the TOUGH+ code architecture, numerical methods, and other issues.

The Problem #3 formulation and the analysis of the results included a mesh-convergence study for both TOUGH+HYDRATE and the TOUGH+HYDRATE+Millstone flow-geomechanical suite. This is the first such study that we are aware of, and contributes to the understanding of the mesh generation methodologies used to create reservoir models for TOUGH+HYDRATE and other Darcy-based hydrate reservoir simulators.

In Q1, the work was expanded to larger cylindrical and planar 2-D systems, to examine the interrelated effects of discretization, mesh design, hydrate saturation, and production strategy on the evolution of the hydrate system, looking for hysteretic effects that could skew the analysis of production behavior.

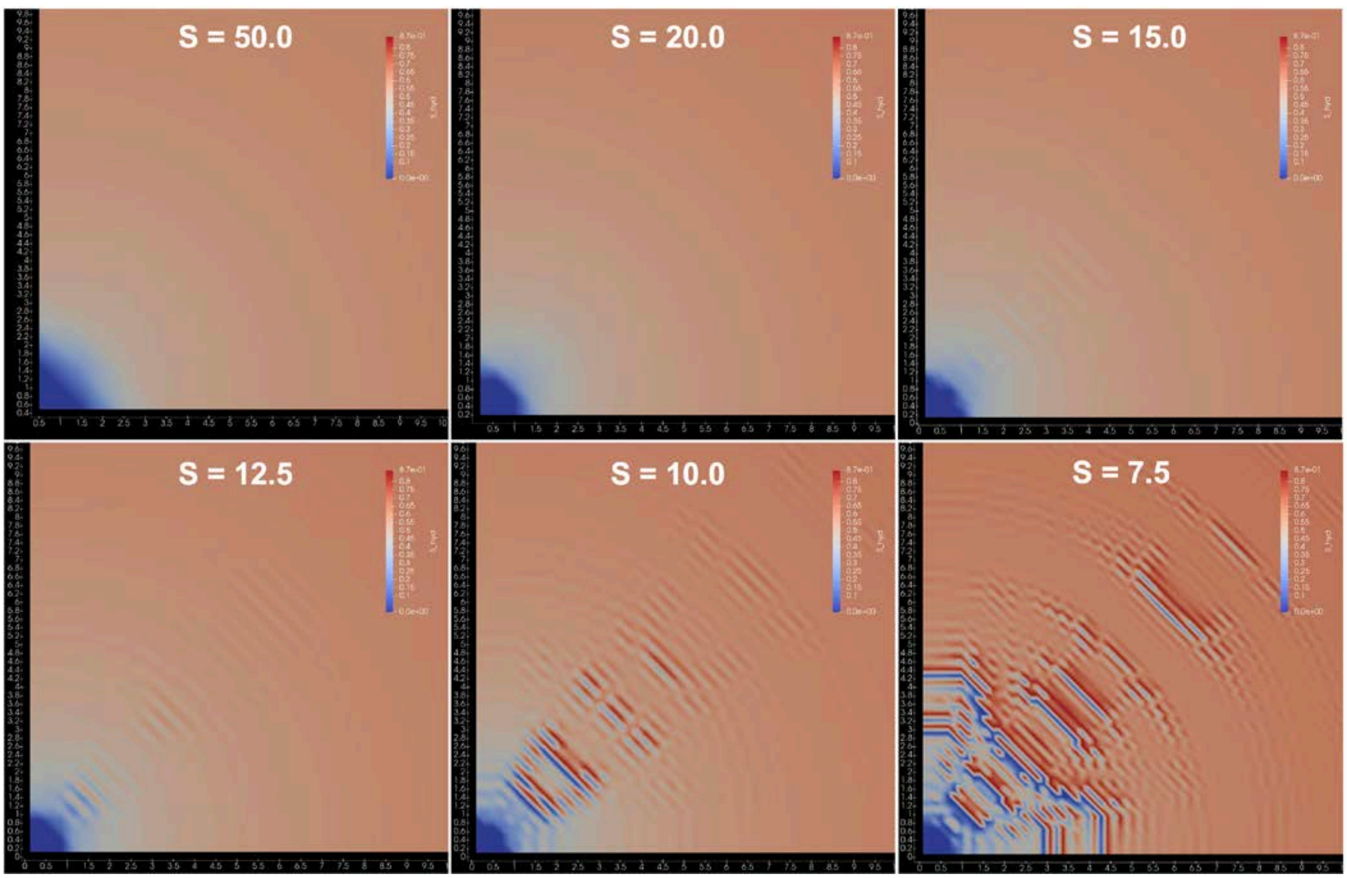

Figure 1: Evolution of a 2D planar hydrate-bearing reservoir (S_H = 0.75) a *t* = 30 days, under a range of discretizations, from *dx* = *dy* = 100 cm to *dx* = *dy* = 15.0 cm.

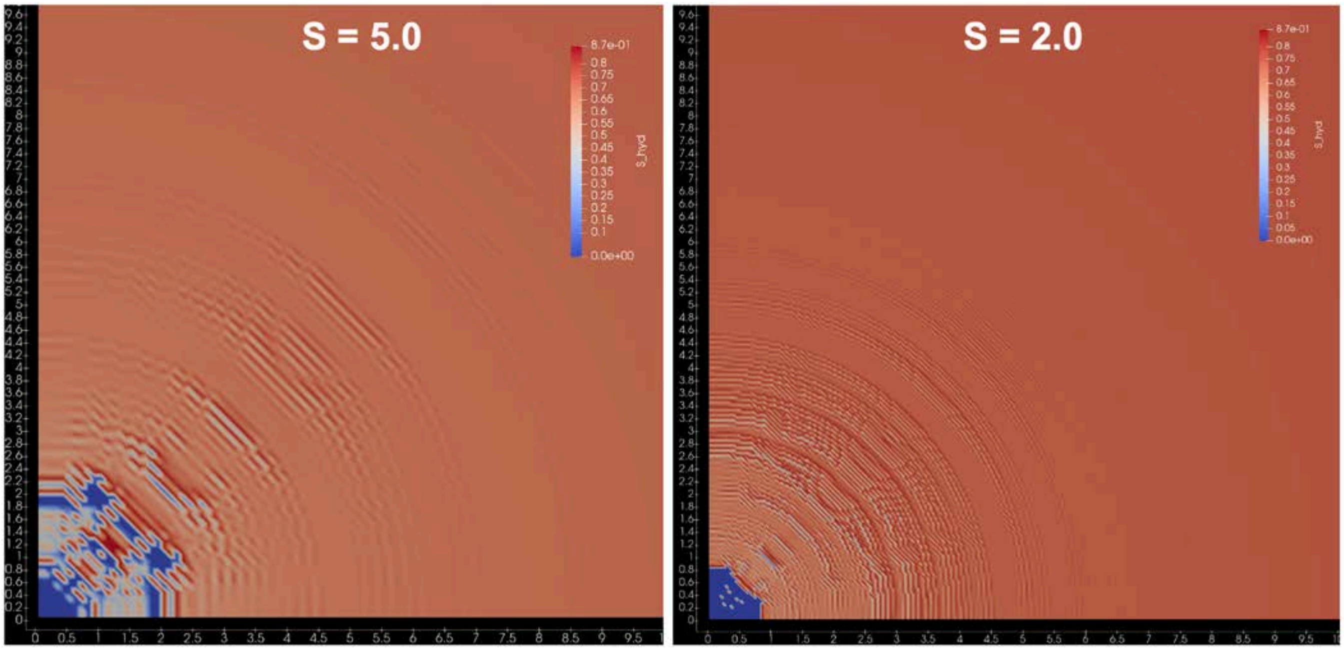

Figure 2: Evolution of a 2D planar hydrate-bearing reservoir (S_H = 0.75) a t = 30 days, under a range of discretizations, from $dx = dy$ = 8.0 cm to $dx = dy$ = 4.0 cm.

There are clear signs of discretization-related effects, with lensing appearing at finer discretizations, and some of this lensing behavior can result in systems with identical initial conditions displaying different longer-term production behavior, depending on mesh resolution. This work was presented at the 2019 AGU Fall Meeting:

“Validation And Testing Of Coupled Flow-Thermal-Mechanical Hydrate Reservoir Models,” OS34A: Geomechanics of Hydrate-Bearing Reservoirs: Laboratory Testing, Numerical Modeling, and Field Testing on Gas Production and Geohazard II.

This analysis will continue in Q2 FY20 and the results will be presented at the 10th International Conference on Gas Hydrates in Singapore, 21-26 June 2020.

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

The work was presented in a talk at the American Geophysical Union Fall Meeting 2019:

“A Trainable Simulator: using unsupervised learning in conjunction with computational methods to rewrite our equations, applied to multiphase flow.” IN44A: Incorporating Physics and Domain Knowledge to Improve Explainability, Reliability, and Generalization of Machine Learning Models I.”

In addition, the work will be presented as an invited presentation at the 2020 SIAM Conference on Mathematics of Data Science:

“On the Interpretation of Learning Dynamical Systems,” Mini Symposium on Machine Learning and Physical Science.

The learning suite was published open source to Github at: https://github.com/afqueiruga/nn_1d_pde

and a preprint of the analysis, “Studying Shallow and Deep Convolutional Neural Networks as Learned Numerical Schemes on the 1D Heat Equation and Burgers' Equation” has been published on arXiv as https://arxiv.org/abs/1909.08142.

Task 5. Publications, Tech Transfer, and Travel
Status: Ongoing

No new submitted publications in this quarter. Two new presentations were given this quarter.

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
4. “Numerical Studies for the Characterization of Recoverable Resources from Methane Hydrate Deposits,” Addressing the Nation’s Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting, Pittsburgh, PA, 26-30 August 2019.
5. AGU Fall Meeting 2019 (2 presentations).

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	April, 2019	Three-paper series describing software published in TiPM.
Deliverable	Report describing the design and performance of the proposed field test.	August 31, 2019	October 7, 2019	Preliminary results presented to DOE in October 2019. Simulations ongoing after receipt of data
Deliverable	Completion participation in the code comparison study; contributions to reports and publications	August 31, 2019	Ongoing	IGHCCS continues into FY20.

Deliverable	An assessment of the feasibility, effectiveness and robustness of ROMs	August 31, 2019	December 31.2019	Development of the ML-based modeling techniques (with associated publications) will be completed in Q1 FY20.

PRODUCTS:

Publications to date (this FWP):

1. 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*, **128**, 405-430, doi: 10.1007/s11242-019-01254-6.
2. 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**, 221-241, doi: 10.1007/s11242-019-01242-w.
3. 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*, **129**, 179-202, doi: 10.1007/s11242-019-01283-1.
4. 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.
5. 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.

Presentations to date (this FWP):

1. “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.
2. “Numerical Studies for the Characterization of Recoverable Resources from Methane Hydrate Deposits,” project wrapup meeting. 28 September 2018.
3. "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.

4. “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.
5. “Numerical Studies for the Characterization of Recoverable Resources from Methane Hydrate Deposits,” Addressing the Nation’s Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting, Pittsburgh, PA, 26-30 August 2019.
6. “A Trainable Simulator: using unsupervised learning in conjunction with computational methods to rewrite our equations, applied to multiphase flow.” IN44A, AGU Fall Meeting, San Francisco, CA, 9-13 December 2019.
7. “Validation And Testing Of Coupled Flow-Thermal-Mechanical Hydrate Reservoir Models,” OS34A, AGU Fall Meeting, San Francisco, CA, 9-13 December 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)**
$120,552	$544,455	$900,000	$355,545	$544,455	$900,000	$355,545

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