Annual Review
Project FWP 72688
Coupled Hydrologic, Thermodynamic, and Geomechanical Processes of Natural Gas Hydrate Production

September 6, 2019

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Pacific Northwest National Laboratory
Topics

• NETL Sponsored Research
  • Tasks and Objectives
  • Accomplishments
  • Outcomes and Lessons Learned
  • Future Research

• Collaborative Research
  • Tasks and Objectives
  • Accomplishments
  • Outcomes and Lessons Learned
  • Future Research
NETL Sponsored Research Tasks and Objectives

BP1-Task 1.0 Project Management
Communication and coordination with NETL project manager on progress against budget and time schedules and alterations to the Project Management Plan, including submission of quarterly reports.

BP1-Task 2.0 IGHCCS2
Second international gas hydrate code comparison study focused on coupled thermal-hydrologic-thermodynamic-geomechanical processes for natural gas hydrate systems

BP1-Task 3.0 STOMP-HYDT-KE Parallelization
Programming implementations for computing on multiple processor computers for both shared-memory and distributed-memory computer architectures for the PNNL developed STOMP-HYDT-KE (Subsurface Transport Over Multiple Phase HYDrate Ternary with Kinetic Exchange) numerical simulator.
NETL Sponsored Research Accomplishments BP1-Task 2.0 IGHCCS2

Principal Investigators
Mark White, PNNL; Tim Kneafsey, LBNL; and Yongkoo Seol, NETL

17 Participating Institutes
NETL Sponsored Research Accomplishments BP1-Task 2.0 IGHCCS2

Benchmark Problems

Benchmark Problem 1 – Similarity Solutions: Hydrate Dissociation in a Radial Domain
Problem Champion: Mark White, PNNL

Benchmark Problem 2 – Extended Terzaghi Problem
Problem Champion: Shubhangi Gupta, GEOMAR

Benchmark Problem 3 – Radial Production
Problem Champions: Matthew Reagan and Alejandro Queiruga, LBNL

Benchmark Problem 4 – Nankai Trough
Problem Champion: Sayuri Kimoto, Kyoto University

Benchmark Problem 5 – Isotropic Consolidation with Hydrate Dissociation
Problem Champions: Shun Uchida, RPI; Xueri Gai, NETL; Jeen-Shang Linn, Pitt; Evgeniy M. Myshakin, NETL and Yongkoo Seol, NETL
# NETL Sponsored Research Accomplishments

**BP1-Task 2.0 IGHCCS2**

Submissions against the Benchmark Problems

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Institute</th>
<th>Teaming</th>
<th>Problem Submissions</th>
<th>Computer Code(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambridge</td>
<td>University of Cambridge</td>
<td>Cambridge + JOGMEC + UCB</td>
<td>Berkeley-Cambridge THM model – COMSOL FEM Code</td>
<td></td>
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<tr>
<td>GEOMAR</td>
<td>GEOMAR Heilmolz Centre for Ocean Research Kiel</td>
<td>GEOMAR</td>
<td>1, 2</td>
<td>TCHM Code for Methane Hydrate Systems</td>
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<tr>
<td>GT</td>
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<td>GT + Ulsan</td>
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<td>Jilin University</td>
<td>JLU</td>
<td>1, 2, 3</td>
<td>HydrateBiot</td>
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<td>JOGMEC</td>
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<td>KAIST</td>
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NETL Sponsored Research Accomplishments  BP1-Task 2.0 IGHCCS2

Publication Status

- Abstract (White, Kneafsey, Seol)
- Introduction (Waite)
- Participants and Computer Codes (White)
- Benchmark Problem 1 (White)
- Benchmark Problem 2 (Gupta)
- Benchmark Problem 3 (Reagan and Queiruga)
- Benchmark Problem 4 (Kimoto)
- Benchmark Problem 5 (Uchida et al.)
- Outcomes for Participants (White, Kneafsey, Seol, Waite)
- Conclusions (White, Kneafsey, Seol)
NETL Sponsored Research Accomplishments BP1-Task 3.0 STOMP-HYDT-KE Parallelization

Shared Memory Parallelization
OpenMP
Lis Linear System Solver

Distributed Memory Parallelization
Global Arrays
Conversion of GA routines to MPI to eliminate the dependency on GA
PETSc Linear System Solver
NETL Sponsored Research Outcomes and Lessons Learned

Benefits to Participants and DOE

Resolution of coding errors

Implementation of gas hydrate capabilities into legacy codes (i.e., GEOS and PFLOTRAN)

More than cursory understand of modeling approaches and code capabilities of international institutes

Identification of needed improvements in simulation capabilities

Comparisons against modeling approaches (e.g., general physics versus built for purpose, equilibrium versus kinetic formulations, finite element versus finite volume, radial geomechanics versus two-dimensional domains).

Legacy of solved hydrate problems for future code development efforts

Creation of an international scientific community for modeling gas hydrate systems
NETL Sponsored Research Outcomes and Lessons Learned

Lessons Learned

Solution Submission Redistribution to Problem Champions

Error – Distributed LBNL results for Benchmark Problem 2 with the wrong units for vertical displacement

Lesson – Extra diligence is required in handling study participants’ results

Presentation of Analytical Results

Error – Incorrectly calculated undrained bulk modulus in the analytical solution for Benchmark Problem 3 and presented results to the study participants

Lesson – Verify calculations with the problem champions before presenting the results

Teaming Arrangements

Error – Incorrectly associated University of Ulsan with Georgia Tech from publications

Lesson – Verify actual teaming arrangements with study participants
NETL Sponsored Research
Future Research

Numerical Modeling of Staged Depressurization in Units D and B

Cylindrical geometry with radially homogeneous properties and saturations
Forecast of produced water and gas
Exploration of intrinsic permeability, effective permeability models, relative permeability models, and bound water

Numerical Modeling of Gas Injection into Monitoring Wells

3D Cartesian geometry with horizontally homogeneous properties and saturations
Potential use of well model
Pure nitrogen injection at different stages of depressurization
Flue-gas injection at different stages of depressurization
Collaborative Research
Tasks and Objectives

Assessment of Nitrogen or Air Injection

Previous simulations demonstrated the potential for flattening the production rates with combined depressurization and pure nitrogen injection, but the economics of pure nitrogen injection makes the technology commercially unviable.

Recognizing the risks associated with air injection, this project seeks to explore the use of air or flue gases for combined depressurization and gas injection.

Required the development of CH₄-O₂-N₂ hydrate equilibria data and conversion of the mobile phases of STOMP-HYDT-KE.
Collaborative Research Accomplishments: Assessment of Nitrogen or Air Injection

- Development of CH₄-O₂-N₂ Gas Hydrate Equilibria
- Computer code based on chemical potential across phases
- Draft manuscript in preparation, entitled “Methane Hydrate Reservoir Modeling with Self-consistent Kihara Parameters.”
NETL Sponsored Research Accomplishments: Assessment of Nitrogen or Air Injection

- Development of CH$_4$-O$_2$-N$_2$ Gas Hydrate Reservoir Simulation Capabilities
  - Conversion of STOMP-HYDT-KE from CH$_4$-CO$_2$-N$_2$ (three phase) to CH$_4$-O$_2$-N$_2$ (two phase)
  - Application of the new simulator to assess nitrogen and air injection in the Ulleung Basin
Collaborative Research Outcomes and Lessons Learned

Outcomes

Pure nitrogen and air injection perform similarly in affecting natural gas hydrate dissociation and production.

Nitrogen can be used as a surrogate for oxygen when modeling gas injection into natural gas hydrate reservoirs.

Flue gas looks promising due to its cost, low flammability risk, and moderate carbon dioxide concentration (i.e., below nonaqueous liquid phase conditions).

Lessons Learned

Nonequilibrium modeling approaches allow for guest molecule swapping investigations, but are computationally expensive (i.e., 9 unknowns per grid cell).

Research sponsored by other nations are not always publicly available.
Collaborative Research
Future Research

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Date: July 29, 2019

Dear Dr. Mark White,

During previous collaboration between KIGAM and PNNL from 2007, we made a remarkable progress in a Gas Hydrate Simulation. With respect to the new proposal to DOE, Korea Institute of Geoscience and Mineral Resources (KIGAM) is highly interested in the simulation study on the Alaska North Slope:

- Implementation of the well models developed for STOMP CO2 and STOMP GT into STOMP HYDE-KF
- Simulation of the depressurization experiments, with consideration of the intrinsic and relative permeability parameter space
- Simulations of gas injection into the monitoring wells, after a period of depressurization

Additionally, KIGAM would like to utilize the STOMP-HYDE-KF simulator as a shadow reservoir simulations in the Utleying Basin at the pilot scale, as a complementary simulator.

As you know, Korea's GH project performed by KIGAM is now preparing next phase with GHDO and Korean government. The work scope and funds for future collaboration project is subject to approval by GHDO and Korean government. If you have any other questions, please feel free to contact us: Joo Yong Lee: jyl@kigam.re.kr, Won Suk Lee: wslee@kigam.re.kr.

Yours sincerely,

Joo Yong Lee, Ph.D.
Project Manager, Gas Hydrate Exploration & Production Study
Collaborative Research
Future Research
Questions?