NATIONAL ENERGY TECHNOLOGY LABORATORY
OIL & GAS

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Quarterly Research Performance Progress Report

(Period Ending 12/31/2019)

Advanced Simulation and Experiments of Strongly Coupled Geomechanics and Flow for Gas Hydrate Deposits: Validation and Field Application

Project Period (10/01/2016 to 12/31/2019)

Submitted by:
Jihoon Kim

The Harold Vance Department of Petroleum Engineering,
College of Engineering
Texas A&M University
501L Richardson Building
3116 College Station TX, 77843-3136
Email: jihoon.kim@tamu.edu
Phone number: (979) 845-2205

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ACCOMPLISHMENTS

Objectives of the project

The objectives of the proposed research are (1) to investigate geomechanical responses induced by depressurization experimentally and numerically; (2) to enhance the current numerical simulation technology in order to simulate complex physically coupled processes by depressurization and (3) to perform in-depth numerical analyses of two selected potential production test sites: one based on the deposits observed at the Ulleung basin UBGH2-6 site; and the other based on well-characterized accumulations from the westend Prudhoe Bay. To these ends, the recipient will have the following specific objectives:

1). Information obtained from multi-scale experiments previously conducted at the recipient's research partner (the Korean Institute of Geoscience and Mineral Resources (KIGAM)) that were designed to represent the most promising known Ulleung Basin gas hydrate deposit as drilled at site UBGH2-6 will be evaluated (Task 2). These findings will be further tested by new experimental studies at Lawrence Berkeley National Laboratory (LBNL) and Texas A&M (TAMU) (Task 3) that are designed capture complex coupled physical processes between flow and geomechanics, such as sand production, capillarity, and formation of secondary hydrates. The findings of Tasks 2 and 3 will be used to further improve numerical codes.

2) Develop (in Tasks 4 through 6) an advanced coupled geomechanics and non-isothermal flow simulator ($T+M^{AM}$) to account for large deformation and strong capillarity. This new code will be validated using data from the literature, from previous work by the project team, and with the results of the proposed experimental studies. The developed simulator will be applied to both Ulleung Basin and Prudhoe Bay sites, effectively addressing complex geomechanical and petrophysical changes induced by depressurization (e.g., frost-heave, strong capillarity, cryo-suction, induced fracturing, and dynamic permeability).

Accomplished

The plan of the project timeline and tasks is shown in Table 1, and the activities and achievements during this period are listed in Table 2.

Task 1: Project management and planning

This project has ended at the date of December 31, 2019. The twelfth quarterly report was submitted to NETL on November 4, 2019. LBNL and TAMU have completed Subtasks 3.3 and 3.4, respectively. Also, the TAMU-KIGAM team have completed Subtasks 4.3, 5.3, 5.4, 5.5, and 5.6 as well as Task 6, and will continue to work on more detailed numerical studies this year although this project ended. The status of the milestones is shown in Table 2. In this quarterly report, we only describe progress of the tasks briefly. The complete and specific descriptions will be included in the final report.

Task 2: Review and evaluation of experimental data of gas hydrate at various scales for gas production of Ulleung Basin

Subtask 2.1 Evaluation of Gas hydrate depressurization experiment of 1-m scale

We have completed this task previously.

Subtask 2.2 Evaluation of Gas hydrate depressurization experiment of 10-m scale

We have completed this task previously.

Subtask 2.3 Evaluation of Gas hydrate depressurization experiment of 1.5-m scale system in 3D

We have completed this task previously.

Subtask 2.4 Evaluation of gas hydrate production experiment of the centimeter-scale system

We have completed this task previously.

Task 3: Laboratory Experiments for Numerical Model Verification

Subtask 3.1: Geomechanical changes from effective stress changes during dissociation

We have completed this task previously.

Subtask 3.2 Geomechanical changes from effective stress changes during dissociation – sand

We have completed this task previously.

Subtask 3.3 Geomechanical changes resulting from secondary hydrate and capillary pressure changes

We have completed this task and reported on this previously. We constructed a custom apparatus and emplaced this in the elastomer sleeve of the LBNL custom hydrate core holder. The apparatus provided pressure ports from a number of locations in the core that access the water phase only (similar to soil moisture probes). As capillary pressure is the difference between the gas and water pressures, measurements of both pressures-either independently or relative to each other- allow its quantification. Sensors or probes in contact with both phases are used (hydrophilic ceramic for the water phase, and the gas phase is connected across a differential pressure transducer). Methane hydrate was formed in the sample using the excess gas method, and the system will be brought to the equilibrium point. A temperature gradient was imposed on the sample such that one end of the sample is outside of hydrate equilibrium, while the other end is still in equilibrium. This test monitored the effect of the secondary hydrate formation resulting from the thermal dissociation. X-ray CT data indicated saturation "migration" in the sample presumably ahead of the temperature gradient, and total quantities of water and methane in the system were quantified allowing estimation of the distributed hydrate saturation.

Additionally, LBNL significantly supported TAMU efforts in devising a new method to measure relative permeability. Following the repair of our CT scanner, all efforts in our Rock Imaging Lab were towards this project. This included the use of 4 high pressure syringe pumps, numerous transducers, data loggers, and the collection of at least 31 sets of CT scans.

Subtask 3.4 Construction of the Relative Permeability Data in Presence of Hydrate

This task is completed. The experimental part of the work is completed. Currently we are working on the data analysis. We plan to perform multi-phase flow studies at varying levels of hydrate saturation in order to construct relative permeability curves that are suitable the depressurization process.

Subtask 3.5 Identification of Hysteresis in Hydrate Stability

We have completed this task previously.

Task 4: Incorporation of Laboratory Data into Numerical Simulation Model

Subtask 4.1 Inputs and Preliminary Scoping Calculations

We have completed this task previously.

Subtask 4.2 Determination of New Constitutive Relationships

We have completed this task previously.

Subtask 4.3 Development of Geological Model

We have completed this task. We have constructed the geological model of PBU-L-106C with mesh files for the same analyses as we did for the UBGH2-6 case by using both TOUGH+ROCMECH and TOUGH+FLAC3D.

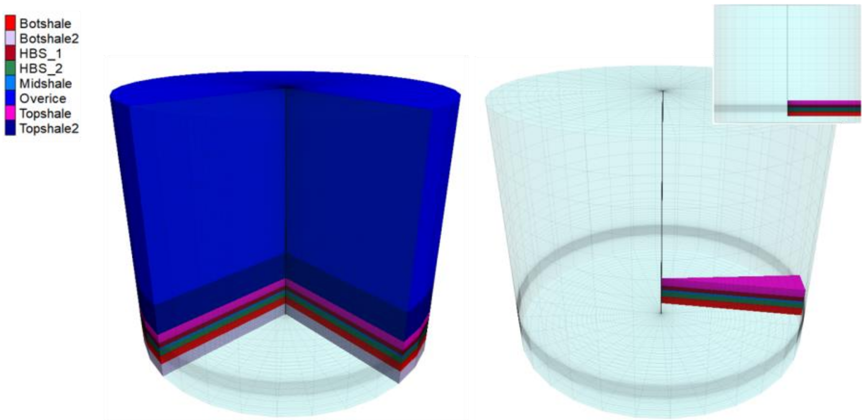

Fig. 4.3.1 Left: Geomechanics model. Right: Flow model

We have also completed the recent geological model for Subtask 5.6 and investigated shear slip and stress concentration near the casing and bottom of the well.

Task 5: Modeling of coupled flow and geomechanics in gas hydrate deposits

Subtask 5.1 Development of a coupled flow and geomechanics simulator for large deformation

We have completed this task previously.

Subtask 5.2 Validation with experimental tests of depressurization

We have completed this task previously.

Subtask 5.3 Modeling of sand production and plastic behavior

We have completed this task. We have implemented the elastoplastic modules in T+M in order to model plastic behavior. Then we can also perform sand production simulation based on elastoplastic geomechanics.

Subtask 5.4 Modeling of induced changes by formation of secondary hydrates: Frost-heave, strong capillarity, and induced fracturing

We have completed this task. We have implemented the subroutines for the capillary hysteresis modeling based on plasticity theory in T+M. We identified behavior of expected hysteretic capillary pressure. Currently, we are numerically modeling fracturing induced by formation of secondary hydrates.

Subtasks 5.5 and 5.6 Field-scale simulation of PBU L106 and Ulleung Basin

We have completed this task. We have revisited and simulated the cases of PBU L106 for more accurate simulation of wellbore behavior and its stability, and the data are currently being processed.

Task 6: Simulation-Based Analysis of System Behavior at the Ignik-Sikumi and Ulleung Hydrate Deposits

We have completed this task. Previously, we have performed numerical simulation on the wellbore slip and stress concentration near the well for the new 2017 UBGH2-6 model. For example, we identified stress concentration at the bottom of the well. About the Ignik-Sikumi deposit, the TAMU-KIGAM collaboration team will continue to complete simulation of the Ignik-Sikumi case this year.

PRODUCTS

No publication or activities were made during this quarter.

BUDGETARY INFORMATION

Table 3 shows the information of the budget for this project and the expenditure up to 12/31/2019. All project funds have been expended. The expenditure by TAMU and cost-share from KIGAM are accurate while the expenditure by LBNL might not be accurate. For detailed information of the budget and expenditure, refer to the financial status report separately submitted to NETL by each institution.

Table 1 – Initial project timeline and milestones (Gantt Chart)

	FY17				FY18				FY19			
Quarter	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4
Task 1.0. Project Management/Planning	A											
Task 2.0. Experimental study of gas hydrate in various scales for gas production of Ulleung Basin												
Subtask 2.1. Depressurization of 1 m scale in 1D				B								
Subtask 2.2 Depressurization of 10-m scale in 1D							C					
Subtask 2.3. Depressurization of 1.5-m scale in 3D										D		
Subtask 2.4. Revisit to the centimeter-scale system												

Task 3.0. Laboratory Experiments for Numerical Model Verification												
Subtask 3.1. Effective stress changes during dissociation				E								
Subtask 3.2. Sand production								F				
Subtask 33. Secondary hydrate and capillary pressure changes												G
Subtask 3.4. Relative Permeability Data												
Subtask 3.5. Hysteresis in Hydrate Stability												
Task 4.0. Incorporation of Laboratory Data into Numerical Simulation Model												
Subtask 4.1. Inputs and Preliminary Scoping Calculations									H			
Subtask 4.2. Determination of New Constitutive Relationships												
Subtask 4.3. Development of Geological Model												
Task 5.0. Modeling of coupled flow and geomechanics in gas hydrate deposits												
Subtask 5.1 Development of a coupled flow and geomechanics simulator for large deformation				I								
Subtask 5.2 Validation with experimental tests of depressurization										J		
Subtask 5.3 Modeling of sand production and plastic behavior								K				
Subtask 5.4 Frost-heave, strong capillarity, and induced fracturing												L
Subtask 5.5 Field-scale simulation of PBU L106												
Subtask 5.6 Field-wide simulation of Ulleung Basin												
Task 6.0. Simulation-Based Analysis of System Behavior at the Ignik-Sikumi and Ulleung Hydrate Deposits												M

Table 2. Milestones Status

Milestone	Description	Planned Completion	Actual Completion	Status / Comments
Task 1 Milestones				
Milestone A	Complete the kick-off meeting and revise the PMP	12/31/17	1/14/2017	Kickoff meeting held 11/22/17, revised PMP finalized 1/17/17
Task 2 Milestones				
Milestone B	Complete analysis of 1 m-scale experiment in 1D and validation of the cm-scale system (FY17, Q4)	9/30/2017		Completed.
Milestone C	Complete analysis of 10m-scale experiment in 1D	6/30/2018		Completed.
Milestone D	Complete analysis of 1.5m-scale experiment in 3D			Completed.
Task 3 Milestones				
Milestone E	Complete geomechanical changes from effective stress changes during dissociation	9/30/2017		Completed

	and construction of the relative permeability data			
Milestone F	Complete geomechanical changes from effective stress changes during dissociation (sand production) and hysteresis in hydrate stability	9/30/2018		Completed
Milestone G	Complete geomechanical changes resulting from secondary hydrate and capillary pressure changes	9/30/2019		Completed
Task 4 Milestones				
Milestone H	Complete inputs and preliminary scoping calculations, determination of New Constitutive Relationships, development of Geological Model	12/31/2018		Completed
Task 5 Milestones				
Milestone I	Complete development of a coupled flow and geomechanics simulator for large deformation, validation with experimental tests of Subtasks 2.1 and 2.4.	9/30/17		Completed
Milestone J	Validation with experimental tests of Task 2 and 3	3/31/2019		Completed
Milestone K	Complete modeling of sand production and plastic behavior, validation with experimental tests of Subtasks 3.3	9/30/2018		Completed
Milestone L	Complete field-scale simulation of the Ulleung Basin and PBU L106	9/30/2019		Completed
Task 6 Milestones				
Milestone M	Complete Task 6	9/30/2019		Completed

Table 3 Budget information

Baselinie Reporting Quarter	Budget Period 1							
	Q1		Q2		Q3		Q4	
	10/01/16-12/31/16		01/01/17-03/31/17		04/01/17-06/30/17		07/01/17-09/30/17	
	Q1	Cumulative Total	Q2	Cumulative Total	Q3	Cumulative Total	Q4	Cumulative Total
Baselinie Cost Plan								
Federal (TAMU)	$37,901	$37,901	$57,809	$95,711	$43,967	$139,678	$34,206	$173,884
Federal (LBNL)	$18,750	$18,750	$18,750	$37,500	$18,750	$56,250	$18,750	$75,000
Non-Federal Cost Share	$6,986	$6,986	$6,986	$13,972	$6,986	$20,958	$656,986	$677,944
Total Planned	$63,637	$63,637	$83,545	$147,183	$69,703	$216,886	$709,942	$926,828
Actual Incurred Cost								
Federal (TAMU)	$0	$0	$10,235	$10,235	$57,085	$67,321	$54,167	$121,488
Federal (LBNL)	$0	$0	$0	$0	$0	$0	$8,500	$8,500
Non-Federal Cost Share	$0	$0	$6,986	$6,986	$6,986	$13,972	$156,986	$170,958
Total incuured cost	$0	$0	$17,221	$17,221	$64,071	$81,293	$219,653	$300,946
Variance								
Federal (TAMU)	($37,901)	($37,901)	($47,574)	($85,475)	$13,118	($72,357)	$19,961	($52,396)
Federal (LBNL)	($18,750)	($18,750)	($18,750)	($37,500)	($18,750)	($56,250)	($10,250)	($66,500)
Non-Federal Cost Share	($6,986)	($6,986)	$0	($6,986)	$0	($6,986)	($500,000)	($506,986)
Total variance	($63,637)	($63,637)	($66,324)	($129,961)	($5,632)	($135,593)	($490,289)	($625,882)

Baselinie Reporting Quarter	Budget Period 2							
	Q1		Q2		Q3		Q4	
	10/01/17-12/31/17		01/01/18-03/31/18		04/01/18-06/30/18		07/01/18-09/30/18	
	Q1	Cumulative Total	Q2	Cumulative Total	Q3	Cumulative Total	Q4	Cumulative Total
Baselinie Cost Plan								
Federal (TAMU)	$42,481	$42,481	$35,307	$77,788	$46,367	$124,155	$39,908	$164,063
Federal (LBNL)	$18,750	$18,750	$18,750	$37,500	$18,750	$56,250	$18,750	$75,000
Non-Federal Cost Share	$6,986	$6,986	$6,986	$13,972	$6,986	$20,958	$6,986	$27,944
Total Planned	$68,217	$68,217	$61,043	$129,260	$72,103	$201,363	$65,644	$267,007
Actual Incurred Cost								
Federal (TAMU)	$35,832	$35,832	$31,662	$67,494	$35,510	$103,004	$86,971	$189,974
Federal (LBNL)	$45,952	$45,952	$18,130	$64,082	$0	$64,082	$4,990	$69,072
Non-Federal Cost Share	$6,986	$6,986	$6,986	$13,972	$506,986	$520,958	$6,986	$527,944
Total incuured cost	$88,770	$88,770	$56,778	$145,548	$542,496	$688,044	$98,947	$786,990
Variance								
Federal (TAMU)	($6,650)	($6,650)	($3,645)	($10,294)	($10,857)	($21,151)	$47,062	$25,911
Federal (LBNL)	$27,202	$27,202	($620)	$26,582	($18,750)	$7,832	($13,760)	($5,928)
Non-Federal Cost Share	$0	$0	$0	$0	$500,000	$500,000	$0	$500,000
Total variance	$20,552	$20,552	($4,265)	$16,288	$470,393	$486,681	$33,302	$519,983

Baselinie Reporting Quarter	Budget Period 3								No cost extension Period	
	Q1		Q2		Q3		Q4		Q1	
	10/01/18-12/31/18		01/01/19-03/31/19		04/01/19-06/30/19		07/01/19-09/30/19		10/01/19-12/31/19	
	Q1	Cumulative Total	Q2	Cumulative Total	Q3	Cumulative Total	Q4	Cumulative Total	Q1	Cumulative Total
Baselinie Cost Plan										
Federal (TAMU)	$43,543	$43,543	$36,189	$79,733	$47,526	$127,259	$41,209	$168,468	$0	$168,468
Federal (LBNL)	$18,750	$18,750	$18,750	$37,500	$18,750	$56,250	$18,750	$75,000	$0	$75,000
Non-Federal Cost Share	$6,986	$6,986	$6,986	$13,972	$6,986	$20,958	$6,986	$27,944	$6,986	$34,930
Total Planned	$69,279	$69,279	$61,925	$131,205	$73,262	$204,467	$66,945	$271,412	$6,986	$278,398
Actual Incurred Cost										
Federal (TAMU)	$46,338	$46,338	$47,068	$93,406	$32,930	$126,336	$48,234	$174,570	$20,228	$194,798
Federal (LBNL)	$6,658	$6,658	$39,707	$46,365	$16,775	$63,140	$67,711	$130,851	$29,600	$160,451
Non-Federal Cost Share	$6,986	$6,986	$6,986	$13,972	$6,986	$20,958	$6,986	$27,944	$6,986	$34,930
Total incuured cost	$59,982	$59,982	$93,761	$153,743	$56,691	$210,434	$122,931	$333,365	$56,814	$390,179
Variance										
Federal (TAMU)	$2,795	$2,795	$10,878	$13,673	($14,596)	($923)	$7,025	$6,102	$20,228	$26,330
Federal (LBNL)	($12,092)	($12,092)	$20,957	$8,865	($1,975)	$6,890	$48,961	$55,851	$29,600	$85,451
Non-Federal Cost Share	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total variance	($9,297)	($9,297)	$31,835	$22,538	($16,571)	$5,967	$55,986	$61,953	$49,828	$111,781

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

13131 Dairy Ashford Road, Suite 225
Sugar Land, TX 77478

1450 Queen Avenue SW
Albany, OR 97321-2198

Arctic Energy Office
420 L Street, Suite 305
Anchorage, AK 99501

Visit the NETL website at:
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1-800-553-7681

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