NATIONAL ENERGY TECHNOLOGY LABORATORY
OIL & GAS

DOE Award No.: DE-FE0028973

Quarterly Research Performance Progress Report

(Period Ending 6/30/2019)

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

Project Period (10/01/2016 to 09/30/2019)

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

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

June 30, 2019

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY
Office of Fossil Energy

DISCLAIMER

TABLE OF CONTENTS

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

The tenth quarterly report was submitted to NETL on April 29, 2019. LBNL and TAMU continue to work on Subtasks 3.3 and 3.4, respectively. TAMU and KIGAM have mainly been focusing on Subtasks 5.2 and 5.6. The specific status of the milestones is shown in Table 2.

KIGAM and TAMU had meetings in Houston and College Station in Texas from May 9 to May 15 and discussed the details of the experimental and numerical results and field application. We participated in the 53rd US Rock Mechanics/Geomechanics Symposium held in New York from June 23 to June 26, and gave presentations. Specific achievements including presentation and publication during this period are as follows.

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

This task was completed.

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

This task was completed.

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

This task was completed.

Fig. 2.3.1 Vertical deformation of the sediment sample measured by a laser displacement gauge during the experiment

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

This task was completed.

Task 3: Laboratory Experiments for Numerical Model Verification

Subtask 3.1: Geomechanical changes from effective stress changes during dissociation

This task was completed.

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

This task was completed.

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

A custom apparatus that was developed for previous tasks was further modified to incorporated capillary pressure sensors (Fig 3.3.1). These ceramic pressure sensors are connected to 1/16 in nylon tubing which was further potted to a 1/8 in stainless steel tube to facilitate pressure sealing. To accommodate three ceramic sensors within the sample, the sample endcap was modified by adding an additional inlet hole (Fig 3.3.2). To prepare the sample, moist sand was packed in an elastomeric sleeve to about 0.3 water saturation, incorporating three capillary sensors in the sand sand at positions near the inlet, mid sample, and near the outlet (Fig 3.3.3). The sleeve was then inserted into an aluminum pressure vessel. With the additional sensor connections, the vessel endcaps were modified so most of the thermocouples, confining fluid ports, and aluminum tubing for cooling/heating were relocated to one endcap, and the inlet/outlet and capillary pressure sensors were located on the other endcap (Fig 3.3.4). The aluminum cooling tubing also was reduced to 3/16 in OD to better fit around sample.

Once assembled, the confining fluid was added. The confining fluid consists of 1:1 solution of propylene glycol and water, with 1% glycerin added to increase viscosity. Confining pressure was set to 100 psi and after confirming no leaks were detected, the system was scanned to check packing and sensor placement (Figs 3.3.5, 3.3.6, 3.3.7).

To monitor the system, three differential pressure transducers have been added, as well as pressure sensors for the confining, inlet, and outlet pressures. Three syringe pumps control fluid pressures and are also logged for flow rate, volume, and pressure.

Status and Plan

Currently the system is packed and in the process of initiating hydrate formation. Due to the complexity of the setup, multiple iterations of the system have been built before the current design which is ready for experimental testing. Methane hydrate will be formed in the sample using the excess gas method, and the system will be brought to the equilibrium point and saturated with water. A temperature gradient will be 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 will monitor the effect of the secondary hydrate formation resulting from the thermal dissociation. This effect will be measured using X-ray CT data showing saturation “migration” in the sample presumably ahead of the temperature gradient, while monitoring total quantities of water and methane in the system allowing estimation of the distributed hydrate saturation.

Fig 3.3.1. Ceramic capillary pressure sensor.

Fig 3.3.2. Packed elastomeric sleeve, showing inlet end cap with two inlets, a central one for fluid flow and temperature measurement, the other to accommodate the three capillary sensors.

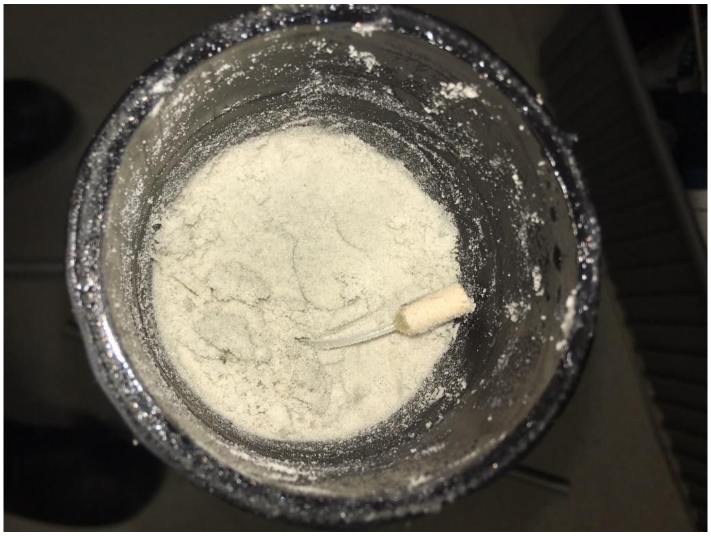

Fig 3.3.3. Packing sensor in sand, inside elastomeric sleeve.

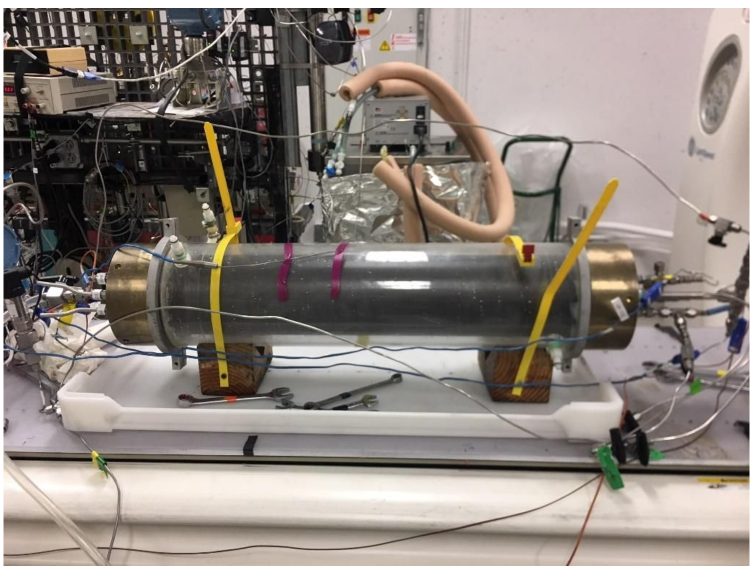

Fig 3.3.4. Assembled Aluminum pressure vessel. The left end has ports for interior coolant flow, confining pressure inlet and outlet, and 4 thermocouples. The right end has inlet port, outlet ports, the three capillary sensor ports, and 4 additional thermocouples.

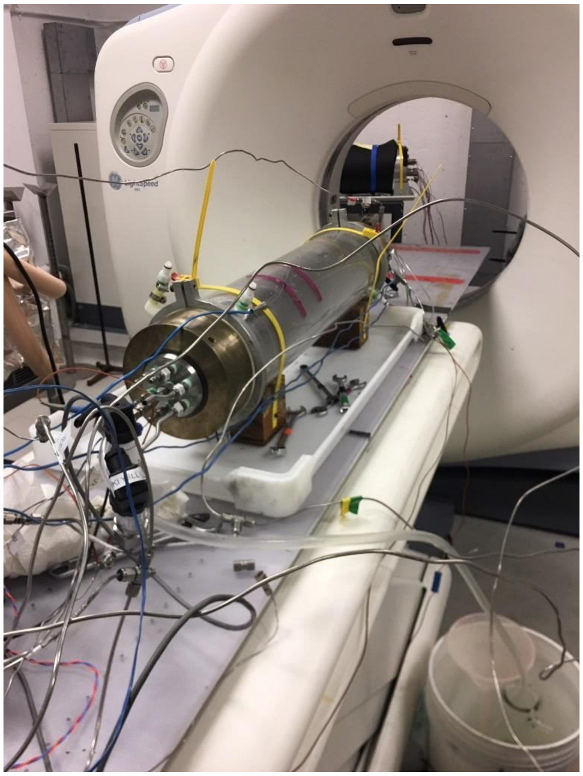

Fig 3.3.5. Vessel on table prepared for scanning.

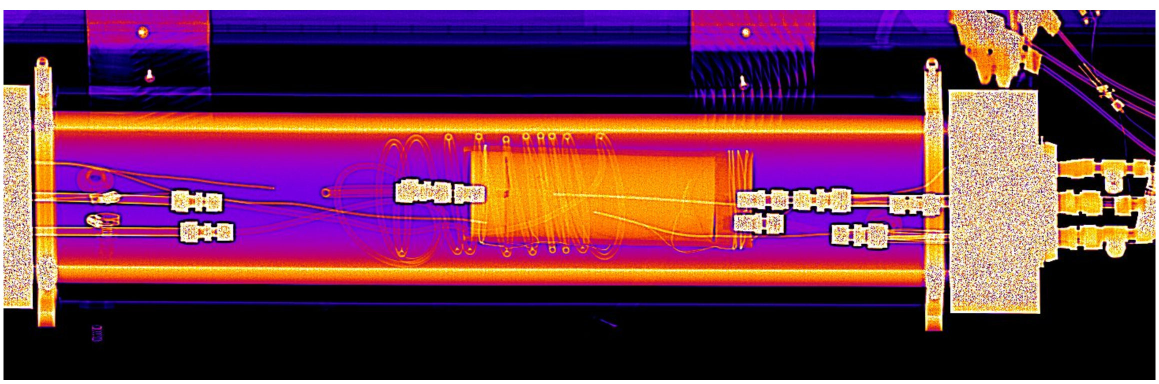

Fig 3.3.6. Initial scan of system to check sensor position and packing. Visible on the right are the two inlet ports. The spiral tubing around the outlet end of the sample is for creating a temperature gradient.

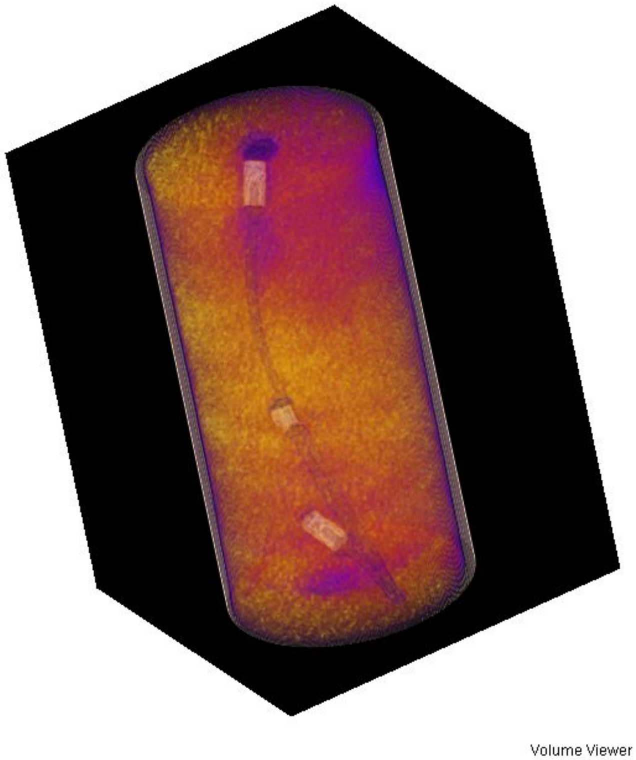

Fig 3.3.7. Scan of sand pack showing location of capillary pressure sensors within the sand.

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

While we are working on this task, we have not obtained visible outcomes, yet.

Subtask 3.5 Identification of Hysteresis in Hydrate Stability

This subtask was competed.

Task 4: Incorporation of Laboratory Data into Numerical Simulation Model

Subtask 4.1 Inputs and Preliminary Scoping Calculations

We have looked into the experimental data of Subtasks 2.1 and 2.3 (e.g., initial saturation, formation types of methane hydrate, previously reported empirical equations of hydrate saturation dependent permeability and geomechanics properties. Those analyses were used in Subtask 5.2.

Subtask 4.2 Determination of New Constitutive Relationships

No further progress has been made during the quarter.

Subtask 4.3 Development of Geological Model

We have been building modified geological models to capture well-bore stability and slip along the well casing, which will be applied to UBGH2-6 (Ulleugn Basin site) and PBU L106 (Alaska). Here, we have updated TOUGH+FLAC3D. Note that T+M(AM) is now used as a term that encompasses TOUGH+ROCMECH and TOUGH+FLAC3D with advanced modules. First, we have been updating the geomechanical model of UBGH2-6, as shown in Fig. 4.3.1, to accurately model failure, wellbore slip or casing failure. We are also updating the geological model of UBGH2-6, shown in Fig. 4.3.2. These modified models will be used for Subtasks 5.5 and 5.6.

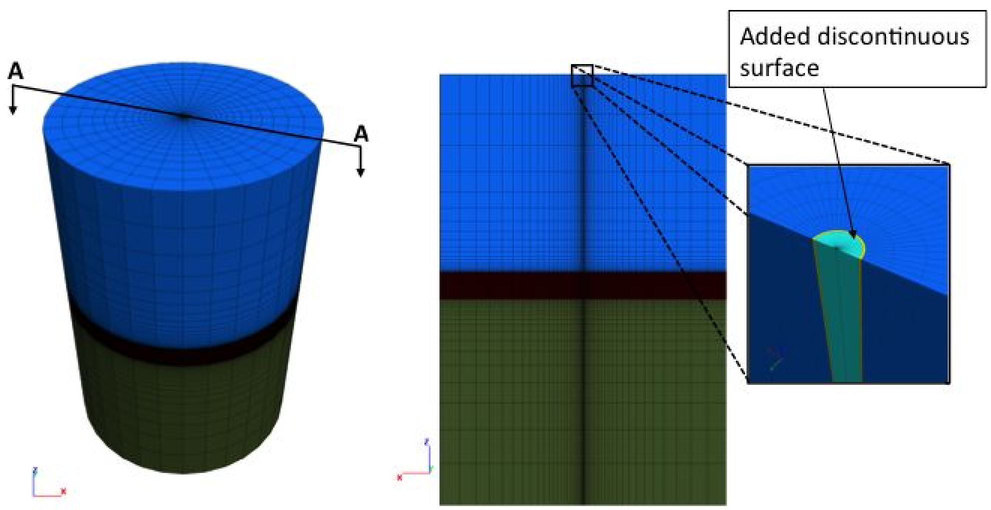

Fig. 4.3.1 A geomechanics model (FLAC3D) with a discontinuous surface along the vertical well

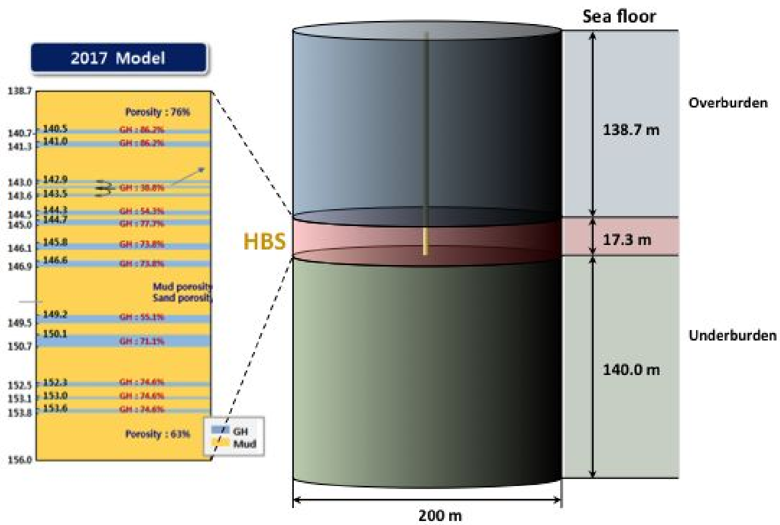

Fig. 4.3.2. The updated geological model for UBGH2-6.

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

This task was completed.

Subtask 5.2 Validation with experimental tests of depressurization

Continuing the previous work, we have been validating TOUGH+ROCMECH, matching parameters of geomechanics and flow by using the data of the sand-muc layer system of Subtask 2.3. We imposed the linear pressure drop at the vertical production nwell, same as the experiment. Figs. 5.2.1 and 5.2.2 show the schematics of numerical simulation and results for validation, respectively.

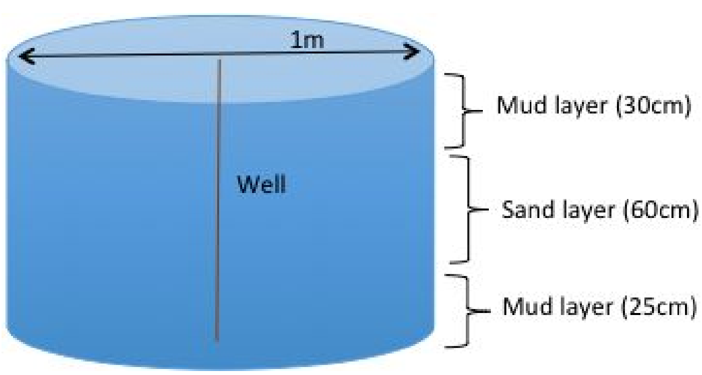

Fig. 5.2.1. Schematics of numerical simulation related to Subtask 2.3. The well was perforated almost through the sand layer.

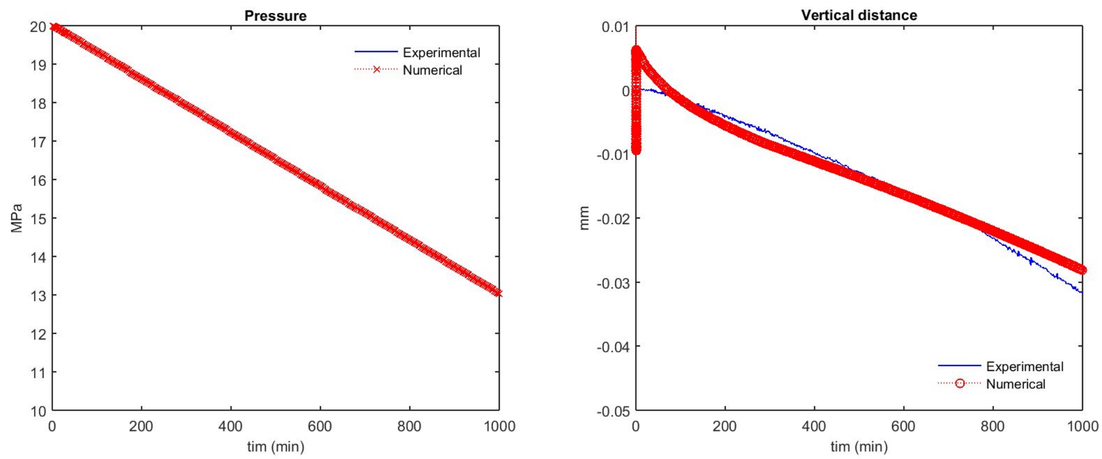

Fig. 5.2.2 Comparison between experimental and numerical results on Subtask 2.3: Pressure (left) and displacement (right). The vertical displacement was measured at the point 25cm away from the well.

Just like the previous 1D case, we used the linear interpolation when estimating the geomechanics moduli. Also, we honor the pressure constraint exactly (the left of Fig. 5.2.2), and tried to match the vertical displacement. Then, we mainly considered the following uncertain parameters: initial hydrate saturation, permeability, drained elastic geomechanics moduli at SH=0% and 100%, where SH means the hydrate saturation.

From the right of Fig. 5.2.2, the numerical result is in good agreement with the experimental results, validating T+M. Still, there are misfits at the early and late times. The misfit at the early time is possibly due to numerical simulation without initialization (i.e., the initial condition did not slightly satisfy the mechanical and thermodynamic equilibriums.). The misfit at the late time might be due to nonlinear relation between hydrate saturation and geomechanics moduli. We will further calibrate the numerical model by tuning initial condition and other flow and geomechanics properties.

Subtask 5.3 Modeling of sand production and plastic behavior

No further progress was made during this quarter.

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

No further progress was made during this quarter.

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

No further progress was made during this quarter.

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

No further progress was made during this quarter.

PRODUCTS

Publication

Journal paper

Yoon H.C., Guo X., Kim J., Killough J., 2019 Flexible and practical parallel implementation for coupled elastoplastic geomechanics and non-isothermal flow. International Journal of Rock Mechanics and Mining Sciences 120:96-107

Conference paper

Kim J., Lee J.Y, 2019, Wellbore stability and possible geomechanical failure in the vicinity of the well during pressurization at the gas hydrate deposit in the Ulleung Basin, 53rd US Rock Mechanics/Geomechanics Symposium, 24-29 Jun, New York, NJ

Yoon S., Kim J., 2019, The fast marching method for simulation of coupled flow and geomechanics and fault activation, 53rd US Rock Mechanics/Geomechanics Symposium, 24-29 Jun, New York, NJ

Yoon S., Lee H., Kim J., Shinn Y.J., 2019, Numerical investigation on geomechanical responses of a pilot-scale CO2 storage site, South Korea, 53rd US Rock Mechanics/Geomechanics Symposium, 24-29 Jun, New York, NJ

The fund was acknowledged in all publications.

Continuing the previous activity of the web-conference, we have been participating in the 2nd International Gas Hydrate Code Comparison Study teleconference (IGHCCS2) held every two weeks online.

BUDGETARY INFORMATION

Table 3 shows the information of the budget for this project and the expenditure up to 6/30/2019. 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 and construction of the relative permeability data	9/30/2017		Completed
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		
Task 4 Milestones				
Milestone H	Complete inputs and preliminary scoping calculations, determination of New Constitutive Relationships, development of Geological Model	12/31/2018		Ongoing
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		Nearly completed

Milestone K	Complete modeling of sand production and plastic behavior, validation with experimental tests of Subtasks 3.3	9/30/2018		Ongoing
Milestone L	Complete field-scale simulation of the Ulleung Basin and PBU L106	9/30/2019		
Task 6 Milestones				
Milestone M	Complete Task 6	9/30/2019		

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							
	Q1		Q2		Q3		Q4	
	10/01/18-12/31/18		01/01/19-03/31/19		04/01/19-06/30/19		07/01/19-09/30/19	
	Q1	Cumulative Total	Q2	Cumulative Total	Q3	Cumulative Total	Q4	Cumulative Total
Baselinie Cost Plan								
Federal (TAMU)	$43,543	$43,543	$36,189	$79,733	$47,526	$127,259	$41,209	$168,468
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	$69,279	$69,279	$61,925	$131,205	$73,262	$204,467	$66,945	$271,412
Actual Incurred Cost								
Federal (TAMU)	$46,338	$46,338	$47,068	$93,406	$32,930	$126,336		
Federal (LBNL)	$6,658	$6,658	$39,707	$46,365	$16,775	$63,140		
Non-Federal Cost Share	$6,986	$6,986	$6,986	$13,972	$6,986	$20,958		
Total incuured cost	$59,982	$59,982	$93,761	$153,743	$56,691	$210,434		
Variance								
Federal (TAMU)	$2,795	$2,795	$10,878	$13,673	($14,596)	($923)		
Federal (LBNL)	($12,092)	($12,092)	$20,957	$8,865	($1,975)	$6,890		
Non-Federal Cost Share	$0	$0	$0	$0	$0	$0		
Total variance	($9,297)	($9,297)	$31,835	$22,538	($16,571)	$5,967		

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:
www.netl.doe.gov

Customer Service Line:
1-800-553-7681

NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

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:
www.netl.doe.gov

Customer Service Line:
1-800-553-7681

NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY