NATIONAL ENERGY TECHNOLOGY LABORATORY
OIL & GAS

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Quarterly Research Performance Progress Report (Period Ending 12/31/2018)

A multi-scale experimental investigation of flow properties in coarse-grained hydrate reservoirs during production

Project Period (10/1/2016-9/30/2019)

Submitted by:
Peter B. Flemings

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Peter Flemings
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Signature

The University of Texas at Austin
DUNS #: 170230239
101 East 27th Street, Suite 4.300
Austin, TX 78712-1500
Email: pflemings@jsg.utexas.edu
Phone number: (512) 475-8738

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Office of Fossil Energy

DISCLAIMER

1. ACCOMPLISHMENTS:

What was done? What was learned?

This report outlines the progress of the first quarter of the third fiscal year in the second budget period. Highlights from the period include:

- We continue to generate controlled synthetic hydrate saturations to achieve specific hydrate saturation targets using different methods in many different chambers

- We made more attempts at seeing methane hydrate in the pore space using MicroCT ko-consolidation cell. We took it as far as we could with the MicroCT equipment we have available up to 4.5 μm/pixel resolution and outline below what could be done by other groups to advance this technology, especially for the fine sediments samples obtained from the Gulf of Mexico, UT-GOM2-1.

- We made several attempts by placing a purchase order with Ryotek to produce a Micro-Raman flow-through chamber (Phase 2) for studying physical and chemical processes of methane hydrate with fluid/gas dynamic flow. After a series of attempts in the past year, the flat sapphire window design did not hold up to the designed pressure. Alternatively, we are seeking to adopt a cylindrical sapphire tube for the system. Commercially-available sapphire tube with rated pressure will ensure the success of building the chamber, although we will have slightly limited viewing window to the hydrate sample in the tube.

A. What are the major goals of the project?

The goals of this project are to provide a systematic understanding of permeability, relative permeability and dissipation behavior in coarse-grained methane hydrate - sediment reservoirs. The results will inform reservoir simulation efforts, which will be critical to determining the viability of the coarse-grained hydrate reservoir as an energy resource. We will perform our investigation at the macro- (core) and micro- (pore) scale.

At the macro- (core) scale, we will: 1) measure the relative permeability of the hydrate reservoir to gas and water flow in the presence of hydrate at various pore saturations; and 2) depressurize the hydrate reservoir at a range of initial saturations to observe mass transport and at what time scale local equilibrium describes disassociation behavior. Simultaneously, at the micro (pore) scale, we will 1) use micro-CT to observe the habit of the hydrate, gas, and water phases within the pore space at a range of initial saturations and then image the evolution of these habits during dissociation, and 2) use optical micro-Raman Spectroscopy to images phases and molecules/salinity present both at initial saturations and at stages of dissociation. We will use our micro-scale observations to inform our macro-scale observations of relative permeability and dissipation behavior.

In Phase 1, we first demonstrated our ability to systematically manufacture sand-pack hydrate samples at a range of hydrate saturations. We then measured the permeability of the hydrate-saturated sand pack to flow a single brine phase and depressurized the hydrate-saturated sand packs and observed the kinetic (time-dependent) behavior. Simultaneously we built a micro-CT pressure container and a micro-Raman Spectroscopy chamber and imaged the pore-scale habit, phases, and pore fluid chemistry of sand-pack hydrate samples. We then made observations on our hydrate-saturated sand-packs.

In Phase 2, we will measure relative permeability to water and gas in the presence of hydrate in sand-packs using co-injection of water and gas. We will also extend our measurements from sand-pack models of hydrate to observations of actual Gulf of Mexico material. We will also measure relative permeability in intact samples to be recovered from the upcoming Gulf of Mexico 2017 hydrate coring expedition. We will also perform dissipation experiments on intact Gulf of Mexico pressure cores. At the micro-scale we will perform micro-Raman and micro-Ct imaging on hydrate samples composed from Gulf of Mexico sediment.

The Project Milestones are listed in the table below.

Milestone Description	Planned Completion	Actual Completion	Verification Method	Comments
Milestone 1.A: Project Kick-off Meeting	11/22/2016 (Y1Q1)	11/22/16	Presentation	Complete
Milestone 1.B: Achieve hydrate formation in sand-pack_Task_2.0_Macro-Scale:	6/27/2017 (Y1Q3)	8/11/17	Documentation of milestone achievement within required project reporting / deliverables (Deliverable 2.1)	Complete, *Documentation in the Y1Q3 quarterly and Phase 1 report*
Milestone 1.C: Controlled and measured hydrate saturation using different methods_Task_2.0_Macro-Scale:_1	3/27/2018 (Y2Q2)	3/27/18	Documentation of milestone achievement within required project reporting / deliverables (Deliverable 2.1)	Complete, *Documentation in Y2Q2 quarterly and Phase 1 report*
3 Milestone 1.D: Achieved depressurization and demonstrated mass balance_Task_3.0_Macro-Scale:	3/27/2018 (Y2Q2)	12/18/2017	Documentation of milestone achievement within required project reporting / deliverables (Deliverable 3.1)	Complete, *Documentation in the Y2Q1 quarterly and Phase 1 report*
Milestone 1.E: Built and tested micro-consolidation device_Task_4.0_Micro-Scale:_1	6/27/2017 (Y1Q3)	6/27/2017	Documentation of milestone achievement within required project reporting / deliverables (Deliverable 4.1)	Complete, *Documentation in Y1Q3 quarterly and Phase 1 report*
Milestone 1.F: Achieved Hydrate formation and measurements in Micro-CT consolidation device_Task_4.0_Micro-Scale:_1	3/27/2018 (Y2Q2)	2/15/18	Documentation of milestone achievement within required project reporting / deliverables (Deliverable 4.1)	Complete, *Documentation in Y2Q2 quarterly and Phase 1 report*
Milestone 1.G: Built and integrated high-pressure gas mixing chamber_Task_5.0_Micro-Scale:	3/27/2018 (Y2Q2)	6/27/17	Documentation of milestone achievement within required project reporting / deliverables (Deliverable 5.1)	Complete, *Documentation in Y1Q3 quarterly and Phase 1 report*
Milestone 1.H: Micro-Raman analysis of synthetic complex methane hydrate_Task_5.0_Micro-Scale:	3/28/2018 (Y2Q2)	3/27/18	Documentation of milestone achievement within required project reporting / deliverables (Deliverable 5.1)	Complete, *Documentation in Y2Q2 quarterly and Phase 1 report*

Milestone 2.A - Measurement of relative permeability in sand-pack cores. (See Subtask 6.1) Task 6.0 Macro-Scale: 2 Task 6.0 Macro -Scale: 2	1/17/2019 (Y3Q2)		Documentation of milestone achievement within required project reporting / deliverables (Deliverable 6.1)	In progress, Expected 9/30/2019 – we are proposing to spend more time refining the experimental process.
Milestone 2.B - Measurement of relative permeability in intact pressure cores. (See Subtask 6.2) Task 6.0 Macro-Scale: 2 Task 6.0 Macro -Scale: 2	9/30/2019 (Y3Q4)		Documentation of milestone achievement within required project reporting / deliverables (Deliverable 6.1)	
Milestone 2.C -Depressurization of intact hydrate samples and documentation of thermodynamic behavior. (See Subtask 7.1 and 7.2) Task 7.0 Macro-Scale: Task 7.0 Macro-Scale:	9/30/2019 (Y3Q4)		Documentation of milestone achievement within required project reporting / deliverables (Deliverable 7.1)	In progress
Milestone 2.D - Achieved gas production from GOM^2 samples monitored by micro-CT. (See Subtask 8.1 and 8.2) Task 8.0 Micro-Scale: Task 8.0 Micro-Scale:	9/30/2019 (Y3Q4)		Documentation of milestone achievement within required project reporting / deliverables Report (Deliverable 8.1)	In progress
Milestone 2.E - Building a chamber to prepare natural samples for 2D-3D micro-Raman analysis; (See Subtask 9.1 and 9.2) Task 9.0 Micro-Scale: Task 9.0 Micro-Scale:	1/17/2019 (Y3Q2)		Documentation of milestone achievement within required project reporting / deliverables (Deliverable 9.1)	In progress
Milestone 2.F - 2D micro-Raman analysis of natural methane hydrate samples at depressurization; (See Subtask 9.1 and 9.2) Task 9.0 Micro-Scale: Task 9.0 Micro-Scale: 1	9/30/2019 (Y3Q4)		Documentation of milestone achievement within required project reporting / deliverables (Deliverable 9.1)	In progress

B. What was accomplished under these goals?

PAST- BUDGET PERIOD 1

Task 1.0 Project Management and Planning

Planned Finish: 09/30/19

Actual Finish: In progress continued in Phase 2, see Task 1 below.

Task 2.0 Macro-Scale: Relative Permeability of Methane Hydrate Sand Packs

Subtask 2.1 Laboratory Creation of Sand-Pack Samples at Varying Hydrate Levels
Planned Finish: 6/ 27/17
Actual Finish: 8/11/17 Complete

Documentation of subtask completion in Y1Q4 Quarterly and the Phase 1 report per the SOPO (Deliverable 2.1).

Subtask 2.2 Steady-State Permeability of Gas and Water of Sand-Pack Hydrate Samples
Planned Finish: 3/27/18
Actual Finish: Complete

Documentation of subtask completion in Y2Q2 Quarterly and the Phase 1 report per the SOPO (Deliverable 2.1).

Task 3.0 Macro-Scale: Depressurization of Methane Hydrate Sand Packs

Subtask 3.1 Depressurization Tests
Planned Finish: 6/27/17
Actual Finish: 3/27/2018 Complete

Documentation of subtask completion in was made in the Phase 1 report per the SOPO (Deliverable 3.1).

Subtask 3.2 Depressurization Tests with CAT scan
Planned Finish: 03/27/18
Actual Finish: 3/27/2018 Complete

Documentation of subtask completion in was made in the Phase 1 report per the SOPO (Deliverable 3.1).

Task 4.0 Micro-Scale: CT Observation of Methane Hydrate Sand Packs

Subtask 4.1 Design and Build a Micro-CT compatible Pressure Vessel
Planned Finish: 6/27/17
Actual Finish: 6/27/2017 Complete

Subtask 4.2 Micro-Scale CT Observations and Analysis
Planned Finish: 03/27/18
Actual Finish: 2/15/2018 Complete

Documentation of Milestone 1.F was included in the Y2 Q2 report and the Phase 1 report per the SOPO (Deliverable 4.1)

Task 5.0 Micro-Scale: Raman Observation of Methane-Gas-Water Systems

Subtask 5.1 Design and Build a Micro-Raman compatible Pressure Vessel
Planned Finish: 6/27/17
Actual Finish: 6/27/17 Complete

Documentation of subtask completion in Y1Q3 Quarterly, Documentation of Milestone 1.G included in the Phase 1 report per the SOPO (Deliverable 5.1)

Subtask 5.2 Micro-scale petrochemistry
Planned Finish: 03/31/18
Actual Finish: 03/27/2018 Complete

Documentation of Milestone 1.H included in the Y2Q2 and Phase 1 report per the SOPO (Deliverable 5.1)

Subtask 5.3 Diffusion kinetics of methane release
Planned Finish: 3/27/18
Actual Finish: 3/27/2018

Documentation of Milestone 1.H included in the Y2Q2 and Phase 1 report per the SOPO (Deliverable 5.1)

Decision Point: Budget Period 2 Continuation

Continuation Application submitted on March 5. Continuation approved March 26, 2018.

CURRENT – BUDGET PERIOD 2

Task 1.0 Project Management and Planning

Planned Finish: 09/30/19
Actual Finish: In progress

This tasks continues from Phase 1.
The eighth Quarter Report was submitted on Oct 31, 2018.

Link to actions for next Quarter, Task 1

Task 6.0 Macro-Scale: Relative Permeability of Methane Hydrate Sand Packs and Intact Pressure Core Samples

Subtask 6.1 Steady-State Relative Permeability Measurements of Sand-Pack Hydrate Samples
Planned Finish: 1/17/19
Actual Finish: In Progress, Expected 9/30/2019 – we are proposing to spend more time refining the experimental process.

The tasks for this quarter involved process improvements for better data collection, including building a cooling jacket for our core holder to minimize internal temperature fluctuations and allow performing experiments in a CT scanner.

Process improvements

Now that we can successfully co-inject gas and water in hydrate bearing samples, we are focused on process improvements to better control our experimental conditions and data collection. In order to better control experimental conditions, we created a cooling jacket to house the core holder which will provide a much more consistent temperature in the core. This jacket allows us to control the temperature by ±0.1°C compared to ±1.0°C without the cooling jacket. The added temperature control allows the sample to remain at three-phase equilibrium and helps the sample to remain homogenous during flow experiments. In addition to the cooling jacket, we have built a stand that will allow us to run our experiments in the UTCT facility. The stand allows the entire experiment to be conducted within the CT lab, and we can now scan our core at any time during the experimental procedure. The CT images will allow us to determine phase saturations as well as to see the spatial distribution of hydrate, gas, and water.

Results

We are able to co-inject gas and brine in the presence of hydrate, however, without scanning the core, we are unable to know the phase saturations and distribution of the hydrate. The results for one of our experiments for co-injection in the presence of hydrate are presented below (Fig. 6.1). In this experiment, the hydrate saturation was approximated to be 25% based on mass balance and quantitative degassing after the experiment.

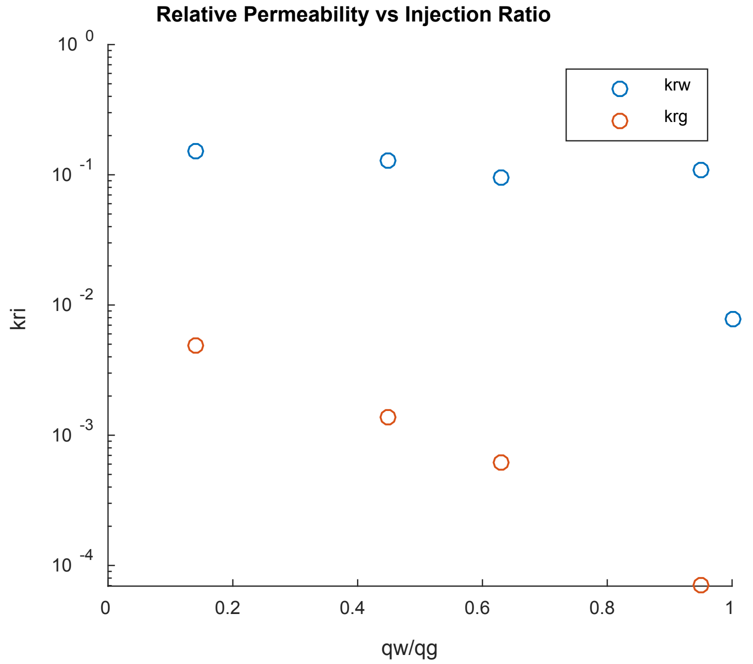

Figure 6.1. Relative permeability to brine (k_{rw}) and gas (k_{rg}) for 5 different injection ratios of gas (q_g) and brine (q_w).

The relative permeability values that were measured were then compared to the relative permeability for the same core without hydrate. Figure 6.2 shows the drop in relative permeability between the core with hydrate and without hydrate.

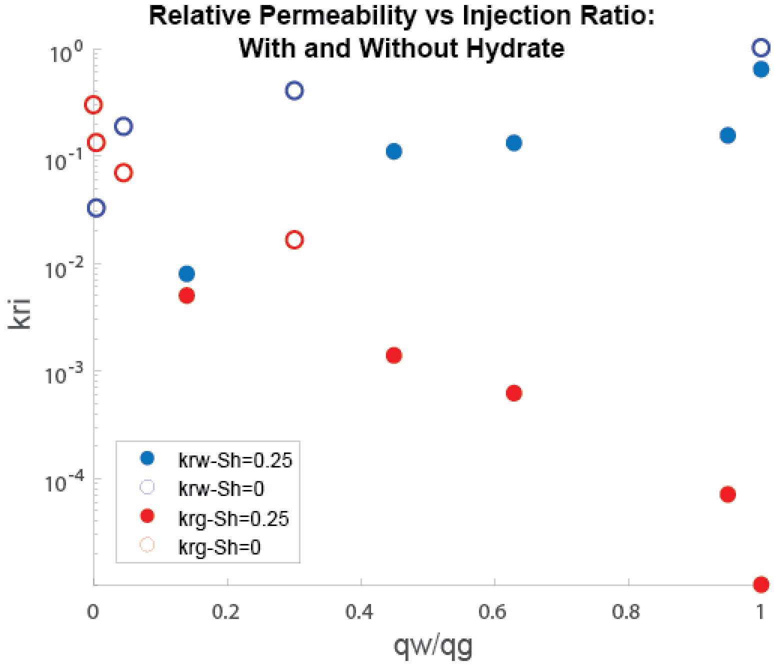

Figure 6.2. Comparison of relative permeability data with and without hydrate. Filled circles: data at 25% hydrate saturation. Open circles: data at 0% hydrate saturation.

During this quarter, we have also begun taking test scans of our core in the UTCT facility. We have scanned the core multiple times without hydrate. These scans allowed us to calibrate our system and to verify our hydrate formation procedure. Our initial conditions are that the core is fully water saturated. This was confirmed with a CT scan. We then displace water from the core to reach 40% water saturation by injecting gas. The core is then scanned at this step to confirm the water saturation as well as the distribution. Initial hydrate formation and distribution is controlled by the distribution of water at this step. The CT scan confirms that the there is a homogenous distribution of water throughout the core.

Link to actions for next Quarter, Task 6

Subtask 6.2 Steady-State Relative Permeability Measurements of Intact Pressure Cores
Planned Finish: 9/30/19
Actual Finish: Not Started

Task 7.0 Macro-Scale: Depressurization of Methane Hydrate Sand Packs and Intact Pressure Core Samples

Subtask 7.1 Depressurization of sand-pack hydrate samples
Planned Finish: 1/17/19
Actual Finish: In Progress

We did not run any depressurization of sand-pack hydrate samples during Q4. We continued to prepare sand pack samples to be formed during Q4 using the excess gas method of Task 2.0. The goal of this work is to observe dissociation behavior across multiple formation methods and a larger range in hydrate saturations.

We have revised and resubmitted a manuscript based on our depressurization experiments from Task 3.0 in sand packs containing hydrate formed with a gas injection method. These results highlight (1) the ability to estimate the sample salinity by monitoring the initial pressure of hydrate dissociation, (2) the deviation of observed pressure during dissociation from the pressure predicted by homogenous conditions, and (3) influence of salt diffusion on the form pressure rebounds. These results show that when hydrate dissociation begins, localized freshening and cooling around the hydrate sets up salinity and heat gradients that change the conditions around the dissociating hydrate.

Link to actions for next Quarter, Task 7

Subtask 7.2 Depressurization of intact pressure cores
Planned Finish: 9/30/19
Actual Finish: In Progress

We depressurized 2 core sections recovered from the northern Gulf of Mexico Green Canyon 955 during UT-GOM2-1. We have now moved on to depressurizing lithofacies-specific samples from uncompromised cores that have never left the hydrate stability field. These samples contained primarily clayey silt lithofacies with variable sandy silt content, with an expected low hydrate saturations. During this dissociation, we allowed for recovery and monitoring of pressure between degassing steps. We calculate a hydrate saturation of 44% of the pore volume. Based on the pressure and temperature of the initial dissociation we estimate an in situ salinity of the sample between 30 to 36 parts per thousand (near seawater concentration).

At this point we have depressurized 7 natural samples with long pressure rebound observations, including sections of high saturation sandy silts, low saturation clayey silts, and sections containing both of these lithofacies. We have begun to analyze some of these data to look at the nature of the pressure rebound both as a pressure versus time (Fig. 7.1) and pressure versus temperature in the context of the methane hydrate phase boundary in multiple salinities (Fig. 7.2). The rate of pressure increase during shut-in periods is limited by the rate of diffusion of heat and salt to the dissociation front, increasing the phase boundary pressure. We are still working on interpreting the rebounds curves, but it appears that over the course of dissociation the rate of pressure recovery is likely limited by a combination of decreased salt concentration gradient during freshening and increased thermal conductivity due to increased gas saturation.

We can monitor the temperature just above the sample in the degassing chamber, and these results reveal cooling in the sample that occurs for several hours as the sample is shut in after each degassing step. This suggests that the endothermic cooling from dissociation is occurring at a rate faster than heat can diffuse into the sample. After several hours the temperature starts to increase and P-T path approaches subparallel to the methane hydrate phase boundary, gradually increasing in salinity1 V. In two subsequent long rebounds of this nature, we see the salinity of the sample decreasing between steps, but slowly increasing over multiple hours, as salt diffuses back to the site of hydrate dissociation.

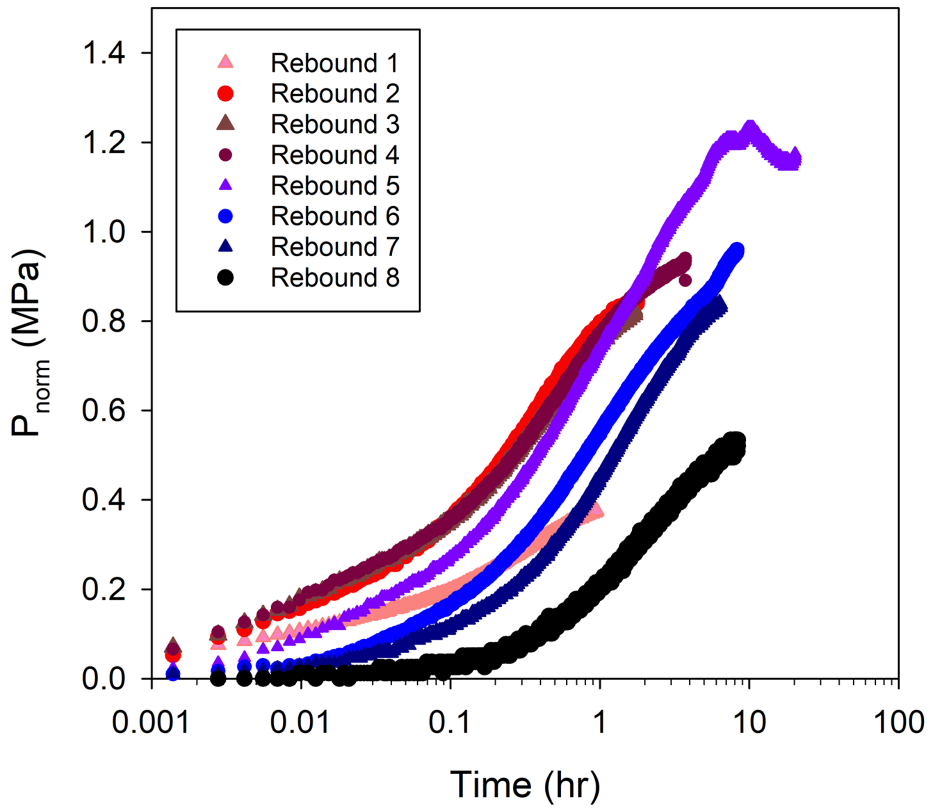

Figure 7.1. Pressure rebounds (normalized to the drop in pressure during each gas release) versus the log of time observed in between degassing steps for natural hydrate sample H002-04CS-1. The shape of the curve shows a slower increase in pressure during dissociation as more of the hydrate has been dissociated.

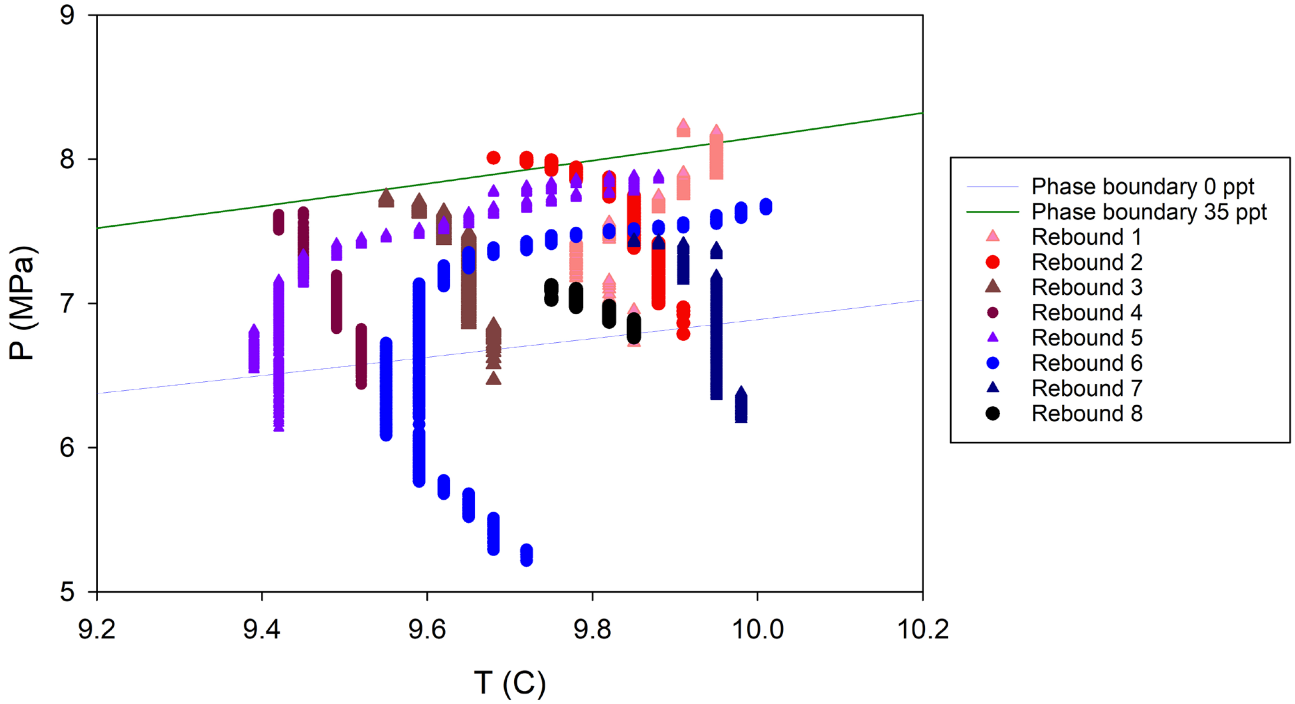

Figure 7.2. Pressure versus temperature for each of the pressure rebounds in H002-04CS-1. Shown with the methane hydrate phase boundary for fresh water (0% NaCl) and seawater (3.5 wt% NaCl). During shorter shut in periods (several hours or less) the temperature adjacent to the sample continues to cool over several hours as the pressure rises. During longer shut-in periods the temperature begins to recover and increase in the sample.

Link to actions for next Quarter, Task 7

Task 8.0 Micro-Scale: CT experiments on Gulf of Mexico Sand Packs

Subtask 8.1 GOM2 Sample Preparation for Micro-CT
Planned Finish: 1/17/19
Actual Finish: In Progress

In the previous quarter we conducted methane hydrate formation experiments in sediment samples from UT-GOM2-1-H005-06FB-2; depth of 429.46 - 429.56 m below sea floor (a sandy silt was identified as Lithofacies 2 in GOM2 studies). The sediment sample was re-compacted from unconsolidated brine-damp sediments. We used KI brine to enhance the contrast between hydrate and brine, and mimic salt exclusion effects during hydrate formation. The X-ray tomography scanning resolution was 4.5 μm/pixel.

With such resolution we are able to observe hydrate in pores sized 20 μm or bigger. The scanning resolution of our equipment and segmentation methods are unable to clearly distinguish hydrate and brine phases from pores smaller than 20 μm. However, the vast majority of pores in this sandy silt are expected to be smaller than 1 μm. Thus, our micro-CT technology is insufficient to clearly distinguish hydrate and brine and observe hydrate pore habit in Lithofacies 2 of GOM2.

With such small grain size, the pore space and hydrates of Lithofacies 2 of GOM2 would be extremely difficult to segment even with a high resolution micro-CT scanner and resolutions of 1-2 μm. Ultimately, we think that it will be necessary to use a synchrotron source with tomography resolution of less than 1 μm in order to image these sediments with X-ray microscopy. However, even with that technology, recognizing hydrate pore-habit in this sandy silt would be challenging.

For the remainder of the project we will concentrate our micro-CT efforts on coarser sediments in which we can clearly distinguish CH_4 hydrates. Our plan is to continue to image pore habit of methane hydrate and to analyze its effect on relative permeability as planned in subtasks 8.1 and 8.2. However, we will use coarser sediments that allow for hydrate/brine segmentation and permit using X-ray to its fullest. We propose to use

- the coarse sand we have been used for Task 4 (Ottawa sand with rounded grains and ~700 μm median grain diameter), and
- a fine sand with grain size ranging from 210 μm to 297 μm used in Task 9.

Subtask 8.2 reports hydrate dissociation experiments for the coarse Ottawa sand.

Link to actions for next Quarter, Task 8

Subtask 8.2 Production Testing on GOM2 Samples Observed with Micro-CT
Planned Finish: 9/30/19
Actual Finish: In Progress

Methane hydrate dissociation experiments in coarse sediments can provide insights for understanding production tests in GOM2 samples. During this quarter we have conducted one methane hydrate dissociation experiment monitored by time-lapse X-ray microtomography. Hydrate was formed in coarse sand utilizing 4.4 wt% KI brine at an initial brine saturation of ~20%. The sandpack was first pressurized to 8.38 MPa using a gas accumulator (excess gas condition) and then brought to the hydrate stability zone by lowering the temperature to 6±1ºC. The dissociation pressure-temperature (P-T) path consisted of gradually lowering gas pressure over 14 days (Figure 8.1). The sandpack reached the dissociation boundary the first day. Dissociation continued slowly for 12 days. The P-T path agreed with the expected hydrate stability lines for 4.4 wt% KI brine and fresh water.

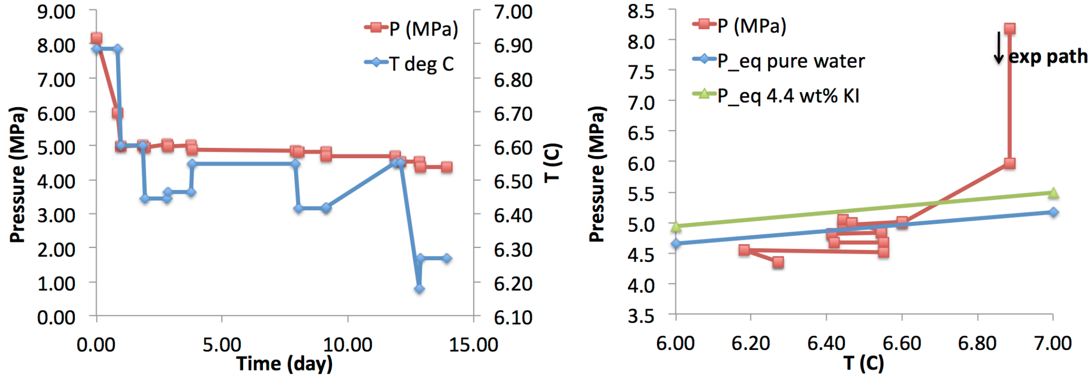

Figure 8.1. Pressure-temperature path during dissociation of methane hydrate in a sand-pack.

Micro-CT images reveal the hydrate-bearing sand-pack structure (Figure 8.2). Ordered according to CT number, the images show: sand and vessel (light gray), hydrate (dark gray), and methane gas (black). Water CT number varies with salinity, from white (concentrated brine) to light gray (fresh water). Hydrate distribution is initially heterogeneous (far left - Before, 8.18 MPa). Most of the methane hydrate accumulates in the pore space near the top of the vessel. Isolated menisci of concentrated brine are observed throughout the sediment pack at grain contacts.

Upon dissociation (see images at 1 day and 2 days), hydrate mass decreases. Hydrate located next to large gas-filled pores and next to the vessel walls dissociate first. Hydrate preferentially dissociates next to the vessel boundaries because of the availability of latent heat transfer for dissociation. At late stages of dissociation, the water from hydrate mixes with concentrated brine and form a connected brine phase with gas and hydrate pockets. The images show a very distinct hydrate/brine/gas habit after dissociation depending on initial hydrate saturation. Ongoing analysis and experiments aim at quantifying these changes and performing dissociation experiments starting from brine-saturated conditions.

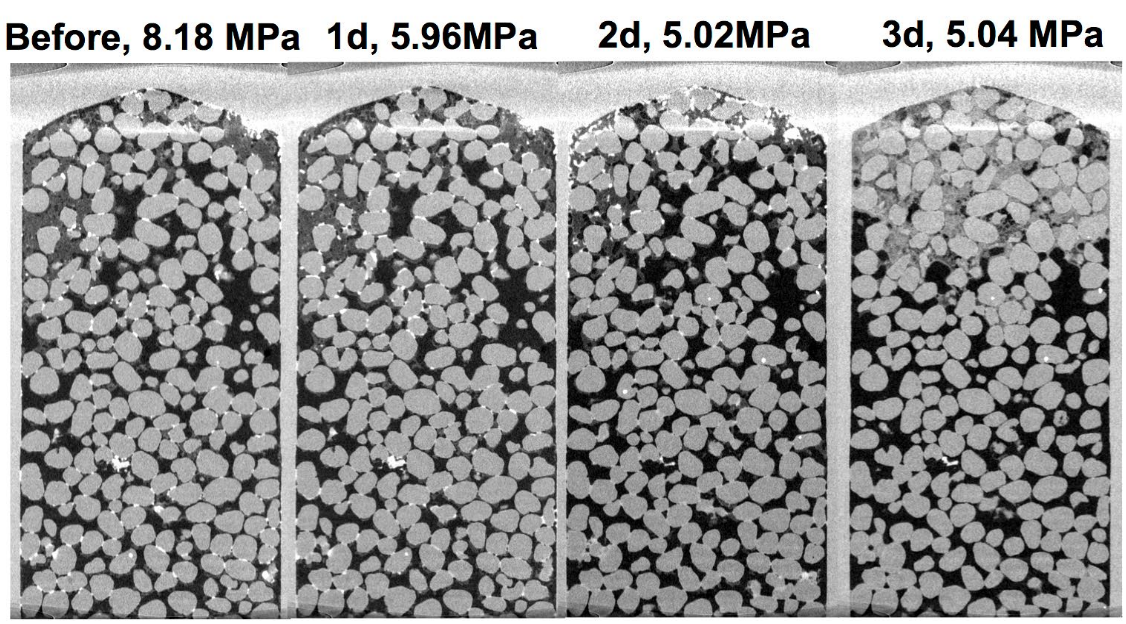

Figure 8.2. Axial slices of micro-consolidation device showing the hydrate-bearing sand-pack. The vessel diameter is 7.9 mm. The images show: sand and aluminum vessel (light gray color), hydrate (dark gray colored porous structure located mostly on the top), methane gas (black color), and brine. The CT number of brine varies with salinity; colors range from white (concentrated brine observed before dissociation) to light gray (fresh water observed upon dissociation). The four images correspond to time-lapse X-ray CT scanning from the time before dissociation (Before, 8.18 MPa) to 3 days into the dissociation path (3d, 5.04 MPa). Notice that hydrate distribution is initially significantly heterogeneous (far left - Before, 8.18 MPa) with hydrate saturation approaching 100% in some areas and approaching 0% a few grains farther away.

Link to actions for next Quarter, Task 8

Task 9.0 Micro-Scale: Raman Observation on hydrate-bearing sand packs

Subtask 9.1 3D Imaging of methane hydrate sandpacks
Planned Finish: 1/17/19
Actual Finish: In Progress

In the previous quarter, we dissociated the methane hydrate experiment in sand and lithofacies 2 (experiment number RH010). In experiment RH010, we loaded 2 kinds of sediments in our Raman chamber—sandy silt and clay-free quartz sand—with 3.5 wt% NaCl solution. The sandy silt sample is from core GC955-H005-06FB-2 (Lithofacies 2) at a depth of 429.46 - 429.56 meter below sea floor. The natural sand has diameters ranging from 210 μm to 297 μm. The dissociation was induced by controlled depressurization at constant temperature. In Figures 9.2 and 9.3, prior to dissociation (at 2040 psi), methane hydrate was initially concentrated in the pore spaces of natural quartz sand; no methane vapor was observed in the sand, but Raman imaging reveals that lithofacies 2 and the mixture contain some methane vapor. Due to grain-sized-induced capillary pressure, methane hydrate is less stable in lithofacies 2 than in sand. During dissociation (at 771 psi), the Raman intensity of methane hydrate decreased as an indication of hydrate dissociation; methane vapor appeared in the sand.

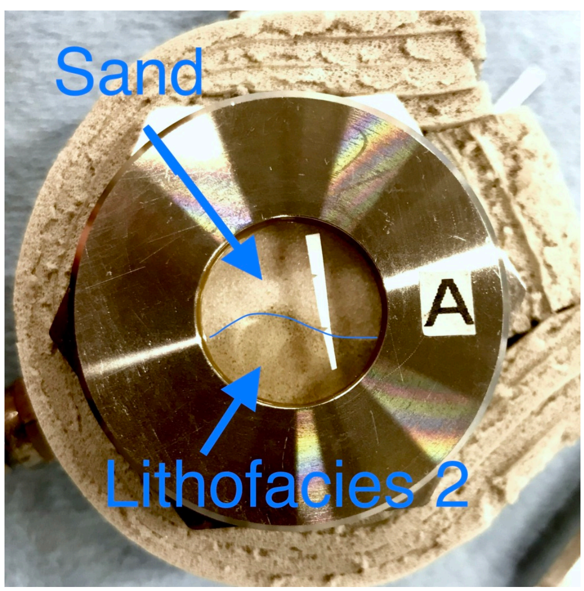

Figure 9.1. Photo of 2 kinds of dry sediments loaded in the Raman chamber prior to hydrate formation: sandy silt from core GC955-H005-06FB-2 (Lithofacies 2) and natural

quartz sand. The mass medium diameter of Lithofacies 2 is 40 μm). The diameters of natural sand range from 210 μm to 297 μm.

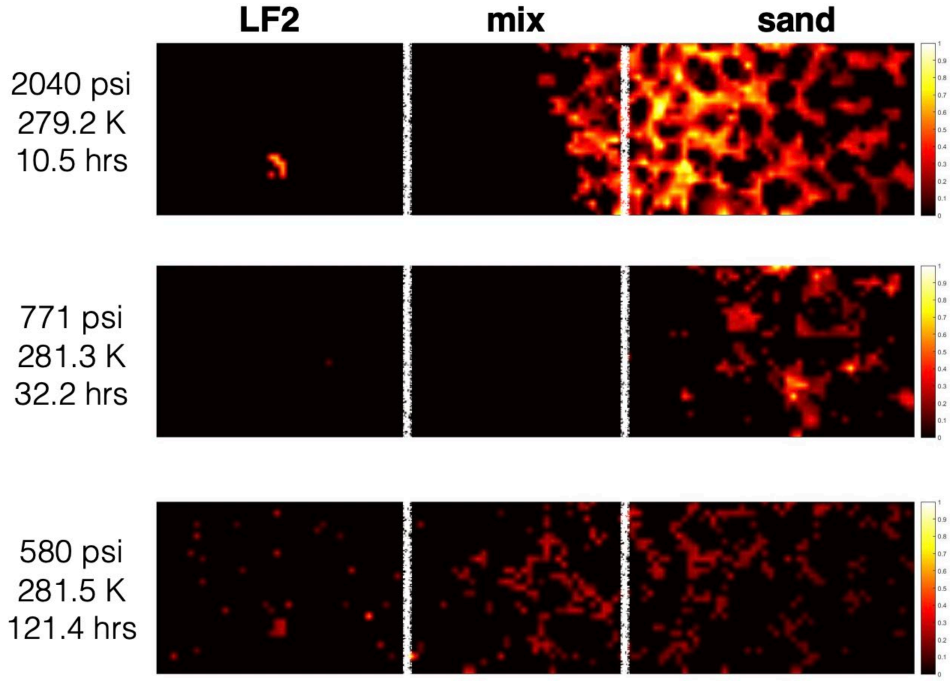

Figure 9.2. Methane hydrate Raman 2D mapping during methane hydrate dissociation in experiment RH010. The mapping was conducted near the boundary of lithofacies 2 (LF2) and sand. Materials and fluids can flow freely across LF2, mixture (mix), and sand layers. Higher intensity (yellow-white color) indicates higher methane hydrate concentration in pore spaces.

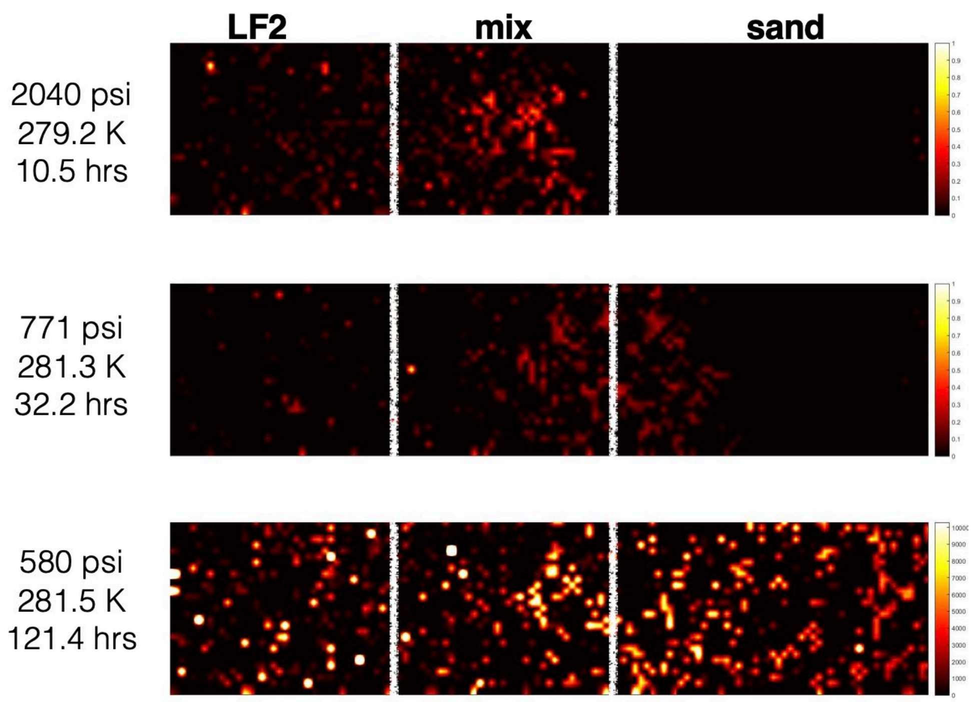

Figure 9.3. Methane vapor Raman 2D mapping during methane hydrate dissociation in experiment RH010. The mapping was acquired at the same position as Figure 9.2. Higher intensity (yellow-white color) indicates higher methane vapor presence in the pore spaces.

Link to actions for next Quarter, Task 9

Subtask 9.2 Micro-Raman Imaging of methane hydrate sandpacks
Planned Finish: 9/30/19
Actual Finish: In Progress

We have been conducting a new methane hydrate formation experiment (experiment number RH011) in glass beads (160 – 210 µm) to repeat a previous experiment (RH009). We deployed a Raman spectrometer to conduct 2D mapping over an area of 3000 µm by 3000 µm. Each Raman data acquisition location is 25 µm apart in both X and Y directions. Through Raman spectroscopy, we used large-to-small Raman peak ratios to indicate methane hydrate structures (ratio of 3 indicating structure I and ratio of 0.5 indicating structure II). Structure-I methane hydrate is the thermodynamically stable structure under the experimental conditions. Raman imaging reveals that the methane hydrate structures are highly heterogeneous in space and time. After 2 hours of the initially methane hydrate formation, parts of methane hydrate reached large-to-small-peak ratio of over 3, while other parts of methane hydrate have low large-to-small-peak ratios (~0.7). Over time, more data points show higher large-to-small-peak ratios, as the methane hydrate slowly moves closer to the thermodynamic equilibrium. Eventually, we expect all the data to lie along the large-to-small-cage ratio of ~3.

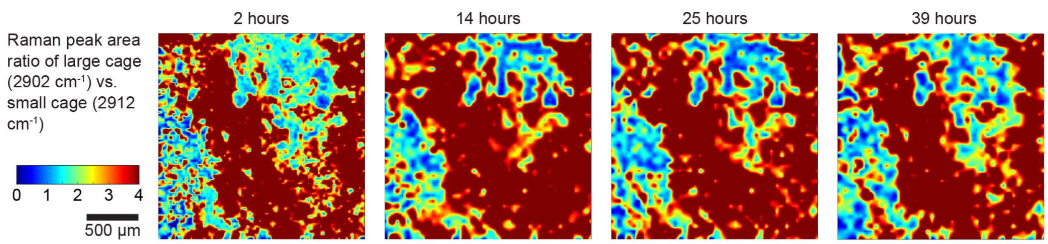

Figure 9.4. Raman 2D mapping of spatial and temporal distributions of methane hydrate large-peak to small-peak area ratios. The spatial heterogeneity of hydrate contents and structures from 2-D Raman mappings. Four columns of data are collected at different times after the initial methane hydrate formation. 2D Raman delineate the spatial distributions of methane hydrate large-to-small-cage ratios over time.

C. What opportunities for training and professional development has the project provided?

We provided technical training and mentoring to 1 high school student and two early college-age students. These students participate in experimental design, research meetings, and experimental measurements. We continue to train 2 doctoral students and 3 post-doctoral scientists.

D. How have the results been disseminated to communities of interest?

- A presentation was made at the Third Deep Carbon Observatory International Science Meeting, St. Andrews, Scotland, 23-25, March.

- A poster was presented at the 9th International Conference on Gas Hydrates, June 25-30, 2017, Denver, CO.
- A poster was presented at the American Geophysical Union Fall Meeting 2017, Dec. 11-15, 2017, New Orleans, LA.
- An invited talk was given at the American Geophysical Union Fall Meeting 2017, December 11-15, 2017, New Orleans, LA.
- Two posters were presented at the Gordon Research Conference- Natural Gas Hydrate Systems, 2018, Feb 25 – March 2, Galveston, TX
- Steve Phillips presented an update on HP3 at the DOE Mastering the Subsurface Through Technology Innovation, Partnerships, and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting in August 2018 in Pittsburgh, PA.
- A poster was presented at the American Geophysical Union Fall Meeting 2018, Dec. 10-14, in Washington DC, entitled "X-Ray Micro-CT Observation of Methane Hydrate Growth in Sandy Sediments"
- A presentation was made at the American Geophysical Union Fall Meeting 2018, Dec. 10-14, in Washington DC, entitled "Pore-Scale Methane Hydrate Formation under Pressure and Temperature Conditions of Natural Reservoirs"
- A poster was presented at the American Geophysical Union Fall Meeting in December 18 in Washington, D.C. entitled "Three phase relative permeability of hydrate bearing sediments."

E. What do you plan to do during the next reporting period to accomplish the goals?

Task 1.0 Project Management and Planning (next quarter plans)

Planned Finish: 09/30/19
Actual Finish: In progress

- Complete the Y1Q1 Quarterly
- Update the HP3 Website

Task 2.0 Macro-Scale: Relative Permeability of Methane Hydrate Sand Packs

Subtask 2.1 Laboratory Creation of Sand-Pack Samples at Varying Hydrate Levels
Planned Finish: 6/27/17
Actual Finish: 6/27/17

Subtask 2.2 Steady-State Permeability of Gas and Water of Sand-Pack Hydrate Samples
Planned Finish: 3/27/18
Actual Finish: 3/27/18

Task 3.0 Macro-Scale: Depressurization of Methane Hydrate Sand Packs

Subtask 3.1 Depressurization Tests
Planned Finish: 6/27/17
Actual Finish: 6/27/17

Subtask 3.2 Depressurization Tests with CAT scan
Planned Finish: 3/27/18
Actual Finish: 3/27/18

Task 4.0 Micro-Scale: CT Observation of Methane Hydrate Sand Packs

Subtask 4.1 Design and Build a Micro-CT compatible Pressure Vessel
Planned Finish: 6/27/17
Actual Finish: 6/27/17

Subtask 4.2 Micro-Scale CT Observations and Analysis
Planned Finish: 3/27/18
Actual Finish: 3/27/2018

Task 5.0 Micro-Scale: Raman Observation of Methane-Gas-Water Systems

Subtask 5.1 Design and Build a Micro-Raman compatible Pressure Vessel
Planned Finish: 6/27/17
Actual Finish: 6/27/17

Subtask 5.2 Micro-scale petrochemistry
Planned Finish: 03/21/18
Actual Finish: 3/27/18

Subtask 5.2 Diffusion kinetics of methane release
Planned Finish: 03/27/18
Actual Finish: 3/27/18

Task 6.0 Macro-Scale: Relative Permeability of Methane Hydrate Sand Packs and Intact Pressure Core Samples (next quarter plans)

Subtask 6.1 Steady-State Relative Permeability Measurements of Sand-Pack Hydrate Samples
Planned Finish: 9/30/19
Actual Finish: In Progress,

The overall goal of this subtask will be to establish a systematic three-phase relative permeability dataset for drainage. The next phase of the project is to run hydrate formation experiments in the new cooling jacket system and then conduct CT scans of the core at multiple points throughout the procedure. We will scan the core to determine initial water saturation and distribution before hydrate formation. Another scan will be taken after hydrate formation to determine how much free gas is remaining in the core and the distribution of the hydrate. We will scan after steady-state is reached for each injection ratio to determine the phase saturation of gas, water, and hydrate. Finally, we will scan the core after all flow experiments have concluded to determine the final hydrate saturation. With the CT images and data, we will be able to determine the relative permeability at phase (water) saturations which can then be compared to models of relative permeability.

Additionally, we have designed an experiment to model hydrate saturation differences between layers of varying grain sizes. This experiment will attempt to model lithofacies 2 and 3, which have a significant contrast in hydrate saturation. The core holder will be packed with alternating layers of 30/50 and 70/140 mesh quartz sand. We will pack the sand at a water saturation of 30%, and form methane hydrate using the excess gas method. After hydrates have been formed, we will take an initial CT scan of the core, close in the core, and continue scanning at 24-hour intervals. The core holder is equipped with a cooling jacket that will maintain the temperature at 6°C. We believe that the hydrate saturation will be homogeneous throughout the core immediately following initial formation, and will slowly shift to a higher saturation in the layers containing larger pores and a lower saturation in the layers with smaller pores.

Subtask 6.2 Steady-State Relative Permeability Measurements of Intact Pressure Cores
Planned Finish: 9/30/19
Actual Finish:

We will start this task by 5/1/19. Since the K0 permeability chamber does not include pressure taps, it will be difficult to assess the relative permeability while correcting for the capillary end effect. However, we do plan to perform coinjection of brine and gas into intact pressure cores to compare the overall pressures and flow rates in comparison with our sand pack and sandstone experiments.

Task 7.0 Macro-Scale: Depressurization of Methane Hydrate Sand Packs and Intact Pressure Core Samples (next quarter plans)

The focus of the remainder of the project will be to better understand the role of salinity during dissociation of hydrate in coarse-grained samples. We have shown that during rapid dissociation the phase boundary rapidly drops to the freshwater phase boundary, but there is a slow recovery in the salinity at the dissociation front when the sample is shut in. In order to better disentangle the role of salt and heat diffusion we will run depressurization experiments in samples with higher hydrate and gas saturation (and lower water saturation) compared to previous experiments. We will also use a simple model of the change in thermal conductivity with increased gas saturation to be able to better account for thermal heat diffusion in interpreting the recovery in salinity at the dissociation front from the recovery in pressure. We will also further analyze pressure and temperature data during dissociation of natural hydrate samples (Subtask 7.2). Through this approach we can measure both temperature and pressure in the sample to better separate the timescales of heat and salt diffusion. We can directly compare the P-T conditions of the sample to the phase boundaries at different salinities.

Subtask 7.1 Depressurization of sand-pack hydrate samples
Planned Finish: 1/17/19
Actual Finish: In Progress

We will form hydrates using the formation method used in Task 2.0 to obtain hydrate saturations > 40% and then depressurize while observing pressure rebound behavior. This will allow us to observe the influence of hydrate saturation and formation method on the form of pressure rebounds. Under these conditions we will be able to observe samples with higher gas saturation than previous experiments to observe differences in the pressure recovery behavior.

Subtask 7.2 Depressurization of intact pressure cores
Planned Finish: 9/30/19
Actual Finish: In Progress

We will depressurize several additional pressure core samples that were recovered during the UT-GOM2-1 Expedition. We will slowly depressurize hydrate-bearing samples of sandy silt and clayey silt while monitoring pressure rebounds between steps during dissociation. This approach will allow us to observe the influence of lithology and hydrate saturation on pressure recovery behavior during dissociation. We will look at the influence of lithofacies (sandy silt vs. clayey silt) and hydrate saturation (5 to 93%) on pressure rebound behavior.

We will synthesize all the results and compare the pressure rebound behavior relative to the phase boundary across the range of lithofacies and hydrate saturations, as well as compare the natural samples to the synthetic experiments.

Task 8.0 Micro-Scale: CT experiments on Gulf of Mexico Sand Packs (next quarter plans)

During the last three quarters of this project we will focus on the observation of methane hydrate, brine and gas habit in sands, and hydrate pore habit varies upon dissociation and production. Our available technology cannot distinguish hydrate from brine in the pore space of sandy silts. Instead we will continue with the understanding and quantification of relative permeabilities in coarse sands.

Subtask 8.1 GOM2 Sample Preparation for Micro-CT
Planned Finish: 1/17/19
Actual Finish: In Progress

We propose to use the following sands instead of GOM2 sediments:

- the coarse sand we have been used for Task 4 (Ottawa sand with rounded grains and ~700 µm median grain diameter), and
- a fine sand with grain size ranging from 210 µm to 297 µm used in Task 9.

These results will be compared to the core-scale measurements of GOM2 samples.

Subtask 8.2 Production Testing on GOM2 Samples Observed with Micro-CT
Planned Finish: 9/30/19
Actual Finish: In Progress

- We will continue with the analysis of two methane hydrate dissociation experiments already performed. These experiments had originally just a small amount of hydrate and started from excess gas conditions.
- We will form methane hydrate in coarse sands with the water-excess method and monitor dissociation with time-lapse X-ray tomography.

Task 9.0 Micro-Scale: Raman Observation on hydrate-bearing sand packs (next quarter plans)

During the last three quarters of this project we will focus on investigating the role of porous media of different sizes that mimic the conditions of GOM2 Lithofacies 2 and 3, on the formation and dissociation of hydrates. This will be achieved through systematic studies of methane hydrate formation and dissociation in glass beads, natural quartz sand, and lithofacies 2 and 3. We will collaborate with Dr. Kehua Yu on numerical modelling of the physical processes (methane diffusion, capillary effect in porous media, length and time scale) to provide physical parameter constraints for understanding GOM2 reservoir.

Subtask 9.1 3D Imaging of methane hydrate sandpacks
Planned Finish: 1/17/19
Actual Finish: In Progress

- We will dissociate the ongoing methane hydrate experiment in glass beads (RH011).

- If time allows, we will pursue the cylindrical sapphire tube design to explore methane hydrate formation and dissociation under pressure and flow gradients.

Subtask 9.2 Micro-Raman Imaging of methane hydrate sandpacks
Planned Finish: 9/30/19
Actual Finish: In Progress

- We will assemble another experiment with silica glass beads of different grain sizes to resemble the previous experiment (RH010) with Lithofacies 2 and natural quartz sand loaded. This experiment will enable us to understand how hydrates crystallize and migrate in GOM^2 pressure-temperature-composition conditions.
- We will conduct an experiment in natural quartz sand in similar thermodynamic conditions as a previous experiment with silica glass beads.

2. PRODUCTS:

What has the project produced?

a. Publications, conference papers, and presentations

Dong, T., Lin, J. F., Flemings, P. B., Polito, P. J. (2016), Pore-scale study on methane hydrate dissociation in brine using micro-Raman spectroscopy, presented at the 2016 Extreme Physics and Chemistry workshop, Deep Carbon Observatory, Palo Alto, Calif., 10-11 Dec.

Lin, J. F., Dong, T., Flemings, P. B., Polito, P. J. (2017), Characterization of methane hydrate reservoirs in the Gulf of Mexico, presented at the Third Deep Carbon Observatory International Science Meeting, St. Andrews, Scotland, 23-25, March.

Phillips, S.C., You, K., Flemings, P.B., Meyer, D.W., and Dong, T., 2017. Dissociation of laboratory-synthesized methane hydrate in coarse-grained sediments by slow depressurization. Poster presented at the 9th International Conference on Gas Hydrates, June 25-30, 2017, Denver, CO.

Chen, X., Espinoza, N., Verma, R., and Prodanovic, M. X-Ray Micro-CT Observations of Hydrate Pore Habit and Lattice Boltzmann Simulations on Permeability Evolution in Hydrate Bearing Sediments (HBS). Presented at the 2017 AGU Fall Meeting, December 11-15, 2017, New Orleans, LA.

Chen, X., & Espinoza, D. N. (2018). Ostwald ripening changes the pore habit and spatial variability of clathrate hydrate. Fuel, 214, 614–622. https://doi.org/10.1016/j.fuel.2017.11.065

Chen, X., Verma, R., Nicolas Espinoza, D., & Prodanović, M. (2018). Pore-Scale Determination of Gas Relative Permeability in Hydrate-Bearing Sediments Using X-Ray Computed Micro-Tomography and Lattice Boltzmann Method. Water Resources Research, 54(1), 600-608. https://doi.org/10.1002/2017WR021851

Chen, X and Espinoza, DN (2018), Surface area controls gas hydrate dissociation kinetics in porous media, Fuel, 234, 358-363. https://doi.org/10.1016/j.fuel.2018.07.030

Chen X, D. Nicolas Espinoza, Nicola Tisato, Peter B. Flemings (2018). X-ray Computed Micro-Tomography Study of Methane Hydrate Bearing Sand: Enhancing Contrast for Improved Segmentation, Gordon Research Conference – Natural Gas Hydrate Systems, Galveston, TX

Chen X, D. Nicolas Espinoza, Nicola Tisato, Rahul Verma, Masa Prodanovic, Peter B. Flemings, (2018). New Insights Into Pore Habit of Gas Hydrate in Sandy Sediments: Impact on Petrophysical and Transport Properties, Gordon Research Conference – Natural Gas Hydrate Systems, Galveston, TX

Chen X, D. Nicolas Espinoza, Nicola Tisato, Peter B. Flemings (2018). "X-Ray Micro-CT Observation of Methane Hydrate Growth in Sandy Sediments", American Geophysical Union Fall Meeting 2018, Dec. 10-14, in Washington DC.

Dong, T., Lin, J.-F., Flemings, P.B., Gu, J.T., Liu, J., Polito, P.J., O'Connell, J. (2017) Pore-scale study on gas hydrate formation and dissociation under relevant reservoir conditions of the Gulf of Mexico, presented at the 2017 Extreme Physics and Chemistry workshop, Deep Carbon Observatory, November 4-5, Tempe, AZ.

Dong, T., Lin, J.-F., Gu, J.T., Polito, P.J., O'Connell, J., Flemings, P.B. (2017), Spatial and temporal dependencies of structure II to structure I methane hydrate transformation in porous media under moderate pressure and temperature conditions, Abstract OS53B-1188 Presented at 2017 Fall Meeting, December 11-15, New Orleans, LA.

Dong, T., Lin, J.-F., Gu, J.T., Polito, P.J., O'Connell, J., Flemings, P.B. (2018), Transformation of metastable structure-II to stable structure-I methane hydrate in porous media during hydrate formation, poster presented at 2018 Jackson School of Geosciences Symposium, Feb. 3, 2018, Austin, TX.

Dong, T., Lin, J.-F., Flemings, P.B., Gu, J.T., Polito, P.J., O'Connell, J. (2018), Pore-scale methane hydrate dissociation in porous media using Raman spectroscopy and optical imaging, poster presented at Gordon Research Conferences on Natural Gas Hydrate Systems, Feb. 25-March 2, 2018, Galveston, TX.

Dong, T., Lin, J.-F., Flemings, P.B., Gu, J.T., Polito, P.J., O'Connell, J. (2018), Pore-Scale Methane Hydrate Formation under Pressure and Temperature Conditions of Natural Reservoirs, American Geophysical Union Fall Meeting 2018, Dec. 10-14, 2018, Washington DC.

Meyer, D.W., Flemings, P.B., DiCarlo, D., You, K., Phillips, S.C., and Kneafsey, T.J. (2018), Experimental investigation of gas flow and hydrate formation within the hydrate stability zone. Journal of Geophysical Research- Solid Earth https://doi.org/10.1029/2018JB015748

Meyer, D., Flemings, P.B., DiCarlo, D. (submitted), Effect of Gas Flow Rate on Hydrate Formation Within the Hydrate Stability Zone, Journal of geophysical research

Meyer, D., PhD Dissertation (submitted) Dynamics of Gas Flow and Hydrate Formation within the Hydrate Stability Zone

Murphy, Z., Fukuyama, D., Daigle, H., DiCarlo, D. (2018), Three-phase relative permeability of hydrate-bearing sediments, poster presented at the American Geophysical Union Fall Meeting, Dec. 10-14, 2018, Washington, D.C.

Phillips, S.C., Flemings, P., You, K., Meyer, D., and Dong, T., submitted. Investigation of in situ salinity and methane hydrate dissociation in coarse-grained sediments by slow, stepwise depressurization.

b. Website(s) or other Internet site(s)

- Project SharePoint: https://sps.austin.utexas.edu/sites/GEOMech/HP3/_layouts/15/start.aspx#/SitePages/Home.aspx
- Project Website

  https://ig.utexas.edu/energy/hydrate-production-properties/

c. Technologies or techniques

Nothing to Report.

d. Inventions, patent applications, and/or licenses

Nothing to Report.

e. Other products

Research Performance Progress Report (Period ending 12/31/16)
Research Performance Progress Report (Period ending 3/31/17)
Research Performance Progress Report (Period ending 6/30/17)
Research Performance Progress Report (Period ending 9/30/17)
Research Performance Progress Report (Period ending 12/31/17)
Research Performance Progress Report (Period ending 3/31/18)
Phase 1 Report (Period ending 3/31/18)
Research Performance Progress Report (Period ending 6/30/18)
Research Performance Progress Report (Period ending 9/30/2018)

3. CHANGES/PROBLEMS:

This section highlights changes and problems encountered on the project.

a. Changes in approach and reasons for change

- Relative Permeability Experiments (Task 6): Since the K0 permeability chamber for measuring intact pressure cores does not include pressure taps, determining accurate relative permeabilities to the gas phase will not be possible because of an unknown degree of capillary end effect. We do plan to continue with coinjection of gas and brine into intact pressure cores, but only as a method of comparison with our sand pack and sandstone results in terms of overall pressure drop and flow rate.

- Microscale Imaging (Task 8): Our available technology is insufficient to clearly distinguish hydrate and brine and observe hydrate pore habit in Lithofacies 2 of GOM2. With such small pore sizes (<1 μm), it would be extremely difficult to segment pore space and hydrate in these silts even doing scans with a high resolution X-ray microtomograph. For this reason, we consulted with the DOE project manager R. Baker and proposed to concentrate our microCT efforts for the remainder of the project on coarser sediments in which we can distinguish CH_4 hydrate clearly. Our plan is to continue to image pore habit of methane hydrate and to analyze its effect on relative permeability as planned in subtasks 8.1 and 8.2. However, we will use coarser sediments that allow for hydrate/brine segmentation and permit using X-ray to its fullest.

- MicroRaman (Task 9): The originally designed semi-cylinderical Flow-Thru Chamber cannot be produced after several attempts in accordance with sapphire specialist Rayotek Scientific Inc., due to technical difficulty. If time allows, we will pursue another design of the Flow-Thru Chamber: a cylindrical sapphire tube that is transparent to Raman imaging. In addition, we have developed a natural sediment chamber to receive samples for Mico-Raman directly from the Pressure Core Analysis and Transfer System (PCATS) that is now being tested.

b. Actual or anticipated problems or delays and actions or plans to resolve them

Nothing to Report.

c. Changes that have a significant impact on expenditures

Nothing to Report.

d. Change of primary performance site location from that originally proposed

Nothing to Report.

4. SPECIAL REPORTING REQUIREMENTS:

Special reporting requirements are listed below.

PAST - BUDGET PERIOD 1

Nothing to Report

CURRENT – BUDGET PERIOD 2

Nothing to Report.

5. BUDGETARY INFORMATION:

The Cost Summary is located in Exhibit 1.

EXHIBIT 1 – COST SUMMARY

Baseline Reporting Quarter	Budget Period 1 (Year 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
Baseline Cost Plan								
Federal Share	$ 283,497	$ 283,497	$ 82,038	$ 365,535	$ 79,691	$ 445,226	$ 79,691	$ 524,917
Non-Federal Share	$ 170,463	$ 170,463	$ 7,129	$ 177,593	$ 7,129	$ 184,722	$ 7,129	$ 191,851
Total Planned	$ 453,960	$ 453,960	$ 89,167	$ 543,128	$ 86,820	$ 629,948	$ 86,820	$ 716,768
Actual Incurred Cost								
Federal Share	$ 6,749	$ 6,749	$ 50,903	$ 57,652	$ 67,795	$ 125,447	$ 162,531	$ 287,977
Non-Federal Share	$ 10,800	$ 10,800	$ 10,800	$ 21,600	$ 10,800	$ 32,400	$ 158,478	$ 190,878
Total Incurred Cost	$ 17,549	$ 17,549	$ 61,703	$ 79,252	$ 78,595	$ 157,847	$ 321,009	$ 478,855
Variance								
Federal Share	$ (276,748)	$ (276,748)	$ (31,135)	$ (307,883)	$ (11,896)	$ (319,779)	$ 82,840	$ (236,940)
Non-Federal Share	$ (159,663)	$ (159,663)	$ 3,671	$ (155,993)	$ 3,671	$ (152,322)	$ 151,349	$ (973)
Total Variance	$ (436,411)	$ (436,411)	$ (27,465)	$ (463,876)	$ (8,226)	$ (472,101)	$ 234,188	$ (237,913)

Baseline Reporting Quarter	Budget Period 1 & 2 (Year 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
Baseline Cost Plan								
Federal Share	$ 109,248	$ 634,165	$ 89,736	$ 723,901	$ 128,914	$ 852,815	$ 106,048	$ 958,863
Non-Federal Share	$ 7,342	$ 199,193	$ 19,369	$ 218,562	$ 7,342	$ 225,904	$ 31,393	$ 257,297
Total Planned	$ 116,590	$ 833,358	$ 109,105	$ 942,463	$ 136,256	$ 1,078,719	$ 137,441	$ 1,216,160
Actual Incurred Cost								
Federal Share	$ 107,216	$ 395,193	$ 154,758	$ 549,951	$ 163,509	$ 713,460	$ 161,083	$ 874,542
Non-Federal Share	$ 19,857	$ 210,735	$ 7,140	$ 217,875	$ 32,567	$ 250,442	$ 7,241	$ 257,683
Total Incurred Cost	$ 127,073	$ 605,928	$ 161,898	$ 767,826	$ 196,076	$ 963,902	$ 168,324	$ 1,132,225
Variance								
Federal Share	$ (2,032)	$ (238,972)	$ 65,022	$ (173,950)	$ 34,595	$ (139,355)	$ 55,035	$ (84,321)
Non-Federal Share	$ 12,515	$ 11,542	$ (12,229)	$ (687)	$ 25,225	$ 24,538	$ (24,152)	$ 386
Total Variance	$ 10,483	$ (227,430)	$ 52,793	$ (174,637)	$ 59,820	$ (114,817)	$ 30,883	$ (83,934)

Baseline Reporting Quarter	Budget Period 2 (Year 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
Baseline Cost Plan								
Federal Share	$ 80,035	$ 1,038,898	$ 53,698	$ 1,092,596	$ 53,698	$ 1,146,294	$ 53,695	$ 1,199,989
Non-Federal Share	$ 7,581	$ 264,878	$ 7,579	$ 272,457	$ 7,579	$ 280,036	$ 19,965	$ 300,001
Total Planned	$ 87,616	$ 1,303,776	$ 61,277	$ 1,365,053	$ 61,277	$ 1,426,330	$ 73,660	$ 1,499,990
Actual Incurred Cost								
Federal Share	$ 52,733	$ 927,275						
Non-Federal Share	$ 7,554	$ 265,237						
Total Incurred Cost	$ 60,287	$ 1,192,512						
Variance								
Federal Share	$ (27,302)	$ (111,623)						
Non-Federal Share	$ (27)	$ 359						
Total Variance	$ (27,329)	$ (111,264)						

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

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