Oil & Natural Gas Technology

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Quarterly Research Performance

Progress Report (Period Ending 09/30/2017)

Dynamic Behavior of Natural Seep Vents: Analysis of Field and Laboratory Observations and Modeling

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

Submitted by:
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Signature

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1 Accomplishments

1.1 Summary of Progress Toward Project Objectives

The *overarching goal* of this project is to develop a computer model to predict the trajectory and dissolution of hydrate-armored methane bubbles originating from natural seeps. The model is based on the Texas A&M Oilspill (Outfall) Calculator (TAMOC), developed by Dr. Socolofsky, and which will be refined and validated through this project to explain fundamental laboratory and field observation of methane bubbles within the gas hydrate stability zone of the ocean water column. *Our approach* is to synthesize fundamental observations from the National Energy Technology Laboratory's (NETL) High-Pressure Water Tunnel (HPWT) and field observations from the Gulf Integrated Spill Research (GISR) seep cruises (cruises G07 and G08), conducted by the PIs in the Gulf of Mexico, to determine the dissolution pathways and mass transfer rates of natural gas bubbles dissolving in the deep ocean water column. We will achieve these objectives by pursuing the *following specific objectives*:

1. Analyze existing data from the NETL HPWT.
2. Synthesize data from the GISR natural seep cruises.
3. Refine and validate the seep model to predict available data.
4. Demonstrate the capability of the seep model to interpret multibeam data.

Ultimately, the *main outcome and benefit* of this work will be to clarify the processes by which hydrate-coated methane bubbles rise and dissolve into the ocean water column, which is important to predict the fate of methane in the water column, to understand the global carbon cycle, and to understand how gas hydrate deposits are maintained and evolve within geologic and oceanic systems, both at present baselines and under climate-driven warming.

The work accomplished during this reporting period focused on the first two specific objectives along with two important Milestones and Decision Point 1. For the NETL HPWT Data, we have completed Subtask 2.1, to evaluate the hydrate formation time. This work involved watching all of the video data available for bubble experiments conducted in the hydrate stability zone (HSZ) in the HPWT facility and characterizing the hydrate shell on the bubbles. For the GISR field data, we have completed development of our analysis tools for the acoustic data and completed Subtask 3.1, to evaluate the bubble size distribution and rise velocity for the high-speed camera

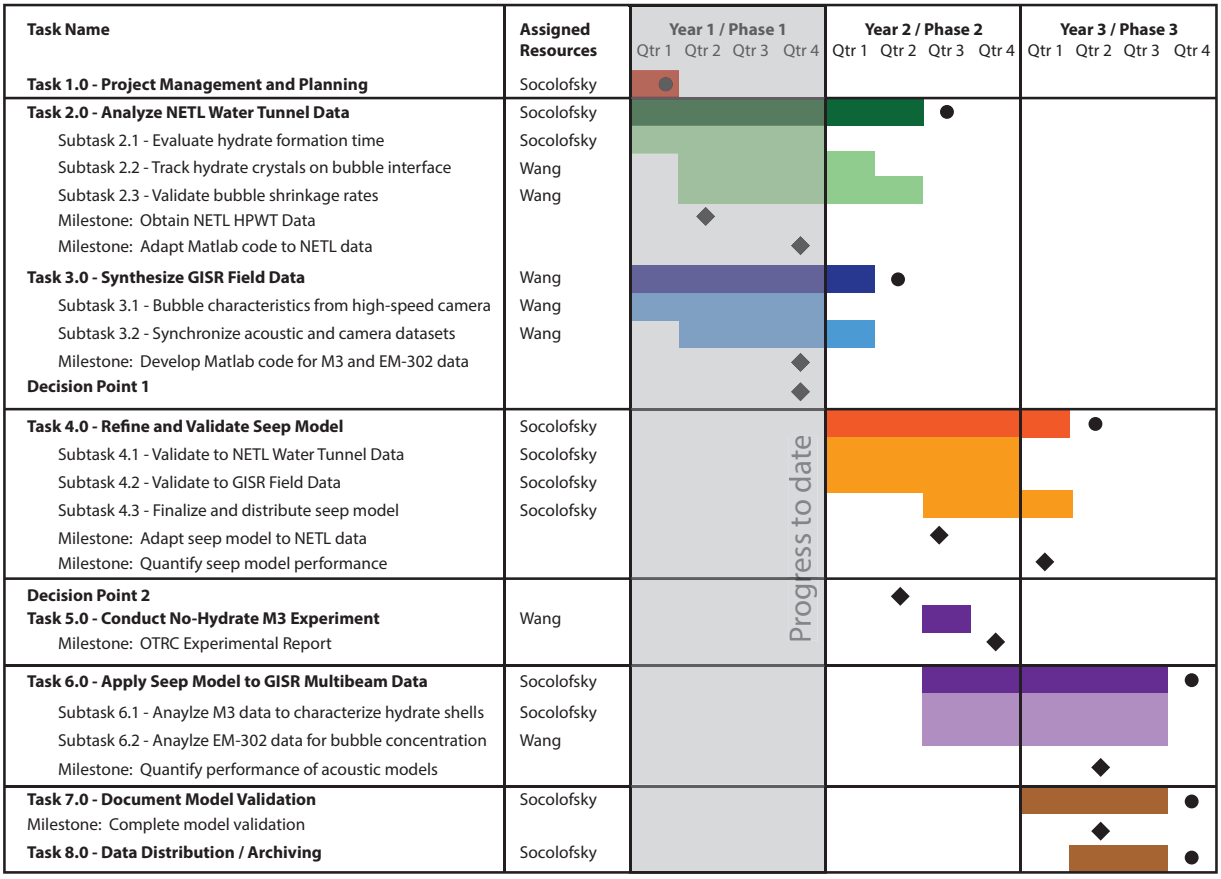

Figure 1: Project Timeline.

data collected during the Gulf of Mexico cruises. The analysis tools we developed for the HPWT data are reported in the report for Milestone 2 (see § 1.4), and the analysis tools for the GISR acoustic data are documented in the report for Milestone 3 (see § 1.4). The post-processed data for Subtasks 2.1 and 3.1 are provided with the report for Decision Point 1 (see § 1.2.4). With the reports submitted for these two new Milestones and for Decision Point 1, the project is currently on schedule.

1.2 Progress on Research Tasks

Figure 1 presents the project timeline, showing each of the project tasks, subtasks, and milestones as identified in the Project Management Plan (PMP). The present reporting period concludes the fourth quarter of FY 2017 (Phase 1 of the project). During this period, we made progress on each subtask of Tasks 2 and 3. We completed Subtasks 2.1 and 3.1 and have submitted the report for Decision Point 1. The work conducted on these tasks during this reporting period is summarized

in the reports for Milestones 2 and 3 and for Decision Point 1. A brief summary of these efforts and their relationship to the overall project is also cataloged in the following sections.

1.2.1 Task 1.0: Project Management Planning

The Project Management Plan was completed during the first quarter of Phase 1 and accepted in final form as of October 28, 2016.

1.2.2 Task 2.0: Analyze NETL Water Tunnel Data

In this project, we will analyze the comprehensive data set of HPWT data collected by NETL. To do this, we have transfered a complete copy of all raw data (primarily image files and time history data of pressure and temperature in the HPWT during each experiment) to Texas A&M University and have installed this data on a secure internal server. Data transfer was completed on March 24, 2017, and achieved Milestone 1 for the project (Obtain NETL HPWT Data). The sections below summarize our progress during the present reporting period in analyzing this data.

Subtask 2.1 - Evaluate Hydrate Formation Time

This subtask has been completed as of September 30, 2017, and all of the post-processed data has been submitted with the report for Decision Point 1 (see § 1.2.4). In this task, we have analyzed all of the video data for bubble experiments in the HPWT that were conducted in the HSZ. From the videos, we identified the moment that hydrate skin coverage was completed for each bubble as well as for key moments when the hydrate dynamics changed. We also synchronized the image data with the measured system pressure, temperature, and operation of the syringe pumps. In the post-processed dataset, we include

- A plot of the pressure and temperature versus time with each of the key moments identified in the video data marked.
- An Excel spreadsheet giving the a description of each event, its time, experimental conditions, and the frame number for the corresponding image in the video sequence.
- A document showing the image capture of the bubble for each key moment identified.

Together, this dataset documents the hydrate formation time for 65 different bubbles, with general conditions as summarized in Table 1. For a complete description of the data analysis for this sub-

Table 1: Summary of individual CH4 and C1C2C3 bubble observations

Gas	**Water**	**# of Bubbles**
CH4	RO Water	21
CH4	Artificial Seawater	7
C1C2C3	RO Water	5
C1C2C3	Artificial Seawater	19
C1C2C3	Artificial Seawater with Dispersant (Corexit)	13

task and the post-processed results, see the full report for Decision Point 1.

Subtask 2.2 - Track Hydrate Crystals on Bubble Interface

This subtask will be the focus of efforts during the first quarter of Phase 2.

Subtask 2.3 - Validate Bubble Shrinkage Rates

During the present reporting period, we have completed development of our image analysis routines to compute bubble sizes for the NETL HPWT dataset. A comprehensive report describing our image analysis methods for this dataset is provided in the report for Milestone 2 (see § 1.4). In the report, we conclude that our image analysis methods agree with the bubble sizes already reported in Warzinski et al. (2014). The Warzinski et al. (2014) Appendices give the shrinkage rates for all experiments conducted outside the HSZ and for image sequences inside the HSZ during which the bubble was coated with a hydrate shell. We will not reprocess any data to obtain shrinkage rates for these data, but instead will use the results reported in Warzinski et al. (2014).

During the next two project quarters, we will analyze additional image data for bubble shrinkage rate during hydrate formation and during dissociation. Some of the data in Warzinski et al. (2014) cover partially-hydrated bubbles, but there are other image sequences for which bubble shrinkage rates can be identified. This work will proceed in parallel with Subtask 2.2. Our hypothesis is that bubble shrinkage rates will be faster (larger mass transfer coefficients) during periods where hydrate crystals are moving on the bubble-water interface. We will test this hypothesis by computing shrinkage rates for bubbles with verified crystal movement based on our work for Subtask 2.2.

Progress Toward Milestones

Milestone 1 (Obtain NETL HPWT Data) was completed on March 24, 2017, and Milestone 2 (Adapt Matlab Code to NETL Data) was completed on September 26, 2017. These Milestones

conclude the Milestones associated with Task 2.

1.2.3 Task 3.0: Synthesize GISR Field Data

The project PIs conducted two research cruises to natural seeps in the Gulf of Mexico under funding to the GISR consortium. These were the G07 cruise in July 2014 to Mississippi Canyon (MC) block 118 and to Green Canyon (GC) block 600 and the G08 cruise in April 2015 to MC 118. Both cruises were on the *E/V Nautilus* and utilized the remotely operated vehicle (ROV) *Hercules*. This project utilizes two main datasets from these cruises: data from our stereoscopic high-speed camera system mounted on the ROV (Wang et al. 2015) and acoustic data collected by an M3 sonar mounted on the ROV and an EM-302 multibeam sonar mounted on the haul of the ship. The image data from the G07 cruise was analyzed previously and reported in Wang et al. (2016). This project will analyze all of the acoustic data and complete analysis of the image data for the G08 cruise. The sections below summarize our progress during the present reporting period in analyzing this field data.

Subtask 3.1 - Bubble Characteristics from High-Speed Camera.

This subtask has been completed as of September 30, 2017, and all of the post-processed data has been submitted with the report for Decision Point 1 (see § 1.2.4). In this task, we have analyzed all of the video data collected from a high-speed, stereoscopic image system deployed on *ROV Hercules* during the two GISR cruises. The video analysis included quantification of the bubble sizes and the rise velocities of individual bubbles. In the report for Decision Point 1, we include an Excel spreadsheet that reports the fitted log-normal distributions for each measurement burst (image sequence) and the mean bubble rise velocity. Together, this dataset documents all of the bubble characteristics data collected from the high-speed camera system during the GISR cruises. In total, 9 measurements at MC 118 and 16 observations at GC 600 were conducted during the cruise in July 2014, and 17 measurements were made at MC 118 in April 2015. For a complete description of the data analysis for this subtask and the post-processed results, see the full report for Decision Point 1.

Subtask 3.2 - Synchronize Acoustic and Camera Datasets.

During the present reporting period we have completed development of our data analysis algorithms to post-process the acoustic data. A comprehensive description of these methods and some sample calculations are presented in the report for Milestone 3. We have also completed our

analysis of the camera image data (see Subtask 3.1, above).

Our focus in the first quarter of Phase 2 will be to compare the measured bubble statistics with the acoustic observations with the goal to calibrate the acoustic observations. For the EM 302, a calibration curve is provided from the manufacturer of the instrument. For the M3, the instrument is uncalibrated, but does produce quantitative acoustic backscatter data. For both datasets, we will determine how well the quantitative acoustic data agree with the measured bubble characteristics (void fraction, bubble size, and flow rate). This is a key step before using the data to validate the numerical model as it will provide a basis for comparing predicted bubble characteristics with the measured acoustic signals.

Progress Toward Milestone

Milestone 3 (Develop Matlab Code for EM 302 and M3 Data) was completed on September 29, 2017. This Milestone concludes the Milestones associated with Task 3.

1.2.4 Decision Point 1

As detailed in the PMP, Decision Point 1, scheduled for the end of Phase 1 has the following two go/no go success criteria:

- Subtask 2.1 (Evaluate hydrate formation time) should be completed in Phase 1. The recipient shall provide to DOE a table of data listing each HPWT experiment and the hydrate formation time evaluated for that experiment. For experiments where the hydrate formation time cannot be evaluated, a comments column shall be included with the table explaining the reason. The completed data table shall demonstrate success of this criterion.

- Subtask 3.1 (Bubble characteristics from high-speed camera) should also be completed in Phase 1. The recipient shall provide to DOE a second table of data listing each high-speed camera dataset for both the 2014 and 2015 GISR cruises and the post-processed values of the median bubble diameter, the standard deviation of a log-normal fit to the volume size distribution, and the mean rise velocity of the bubbles. The completed data table shall demonstrate success of this criterion.

During the present reporting period, we have completed a report for Decision Point 1, which includes digital appendices containing all of the post-processed data described in the two success criteria

above. Based on successful completion of these go/no go success criteria, we request permission to begin Task 4 (Refine and Validate Seep Model).

1.3 Deliverables

To date, we have completed the following list of deliverables:

1. **Project Management Plan (PMP)**. The PMP was delivered in its accepted and final form on October 28, 2016.

2. **Data Management Plan (DMP)**. No revisions were requested by the Project Officer to the plan submitted with the proposal; hence, the original DMP is the present guiding document. Revisions will be updated as necessary throughout the project as required by the Project Officer.

In the present reporting period, no new deliverables were due. The next set of deliverables include complete archives of the analysis data produced through analysis of the HPWT and GISR Seep Cruise data. Progress toward these deliverables is summarized above in the reporting for each Task.

1.4 Milestones Log

Table 2 presents the schedule of milestones with their verification methods for the duration of the project period. Milestone 1 was completed on time. Milestones 2 and 3 were also completed during the present reporting period, and were completed on time. See Section 1.2 for details on progress toward completion of up-coming milestones, which are proceeding on schedule.

1.5 Plans for the Next Reporting Period

Work for the next reporting period will continue on Tasks 2 and 3 and will begin Task 4 (refer to Figure 1). For Task 2, we will focus on tracking hydrate crystals on the bubble-water interface during hydrate formation and dissociation (Subtask 2.2). We will also analysis the image data to obtain bubble shrinkage rates for periods during which hydrate crystals are moving on the bubble-water interface (Subtask 2.3). Once this work is completed, Task 2 will be complete.

For Task 3, we will use the measured bubble characteristics from the images (Subtask 3.1) to compare with the quantitative acoustic data (Subtask 3.2). By this comparison we will evaluate the

Table 2: Milestones schedule and verification methods.

	Milestone	**Comments**
Title	Acquisition of NETL HPWT data	
Date Completed	March 24, 2017	
Verification Method	Email verification	
Title	Adapt Matlab code to NETL data	
Date Completed	September 28, 2017	
Verification Method	Report	
Title	Matlab code for M3 and EM-302 data	
Date Completed	September 29, 2017	
Verification Method	Report	
Title	OTRC Experimental Report	
Planned Date	August 2018	
Verification Method	Report	
Title	Adapt seep model to NETL data	
Planned Date	June 2018	
Verification Method	Report	
Title	Quantify seep model performance	
Planned Date	December 2018	
Verification Method	Report	
Title	Quantify performance of acoustic models	
Planned Date	March 2019	
Verification Method	Report	

calibration for target strength for the EM 302 and will develop an understanding of the backscatter data for the M3. Once this work is completed, Task 3 will be complete.

We are working on two journal manuscripts stemming from Tasks 2 and 3. For Task 2, we will report on the measured hydrate formation time, comparing to our empirical relationship for hydrate formation time, and will use the bubble shrinkage rate data to evaluate mass transfer coefficients for the complete HPWT dataset. For Task 3, we are drafting a manuscript to report the major finding for the second GISR cruise, G08.

For Task 4, we will begin comparing our numerical model to the data obtained in Tasks 2 and 3. For the next reporting period, we will compare the observed hydrate formation times with the time predicted by our empirical model. This is a key step in validating the hydrate formation mechanisms in our model.

References

Warzinski, R. P., F. Shaffer, R. Lynn, I. Haljasmaa, M. Schellhaas, B. J. Anderson, S. Velaga, I. Leifer, and J. Levine (2014), The role of gas hydrates during the release and transport of well fluids in the deep ocean, DOI/BSEE Contract E12PG00051/M11PPG00053, Final Report, U.S. Department of Energy, National Energy Technology Laboratory.

2 Products

2.1 Publications, Conference Papers, and Presentations

Nothing to report

2.2 Websites or Other Internet Sites

The natural seep model used for this project, the Texas A&M Oilspill Calculator (TAMOC), is published via an open source code sharing service at:

http://github.com/socolofs/tamoc

2.3 Technologies or Techniques

Nothing to report.

2.4 Inventions, Patent Applications, and/or Licenses

Nothing to report.

2.5 Other Products

Nothing to report.

3 Participants and other collaborating organizations

3.1 Project Personnel

- 1. **Name**: Scott A. Socolofsky
  2. **Project Role**: Principal Investigator
  3. **Nearest person months worked during reporting period**: 1
  4. **Contribution to Project**: Overall project management and direction. Dr. Socolofsky has led the collection of the HPWT data, directed the data analysis methods, and completed all project reporting requirements.
  5. **Collaborated with individual in foreign country**: No
  6. **Travelled to foreign country**: No

- 1. **Name**: Binbin Wang
  2. **Project Role**: Co-Principal Investigator
  3. **Nearest person months worked during reporting period**: 2
  4. **Contribution to Project**: Analyzed the image data for the G08 cruise, created model for acoustic data from M3 sonar and EM-302 multibeam, and compared the measured data to model results from TAMOC. He also trained the Ph.D. student to begin analysis of the NETL HPWT data.
  5. **Collaborated with individual in foreign country**: No
  6. **Travelled to foreign country**: No

- 1. **Name**: Byungjin Kim
  2. **Project Role**: Ph.D. Student
  3. **Nearest person months worked during reporting period**: 3
  4. **Contribution to Project**: Organized the HPWT data, summarized the existing results from the NETL reports, and analyzed HPWT data for bubble size, hydrate formation time, and bubble interface mobility.
  5. **Collaborated with individual in foreign country**: No
  6. **Travelled to foreign country**: No

- 1. **Name**: Soobum Bae
  2. **Project Role**: Ph.D. Student
  3. **Nearest person months worked during reporting period**: 3
  4. **Contribution to Project**: Soobum Bae is working as an unfunded Master of Science student to help analyze the HPWT data. He has helped to classify the video image data and to evaluate the hydrate equation of state.
  5. **Collaborated with individual in foreign country**: No
  6. **Travelled to foreign country**: No

3.2 Partner Organizations

None to report.

3.3 External Collaborators or Contacts

This project works in close collaboration with researchers in the DOE/NETL funded project "Fate of Methane in the Water Column," led by the U.S. Geological Survey (USGS) in Woods Hole (Carolyn Ruppel), and with a new project led by the University of Rochester (John Kessler) to advance understanding of the environmental implications that methane leaking from dissociating gas hydrates could have on the ocean-atmosphere system. Dr. Socolofsky visits and communicates with researchers in these projects regularly and shares updates on work in progress. Accomplishments associated with these collaborations are detailed in Section 1.

4 Impact

None at this point.

5 Changes / Problems

Personnel. Salary for the post-doc, Binbin Wang, has now posted to the project, and our spend rate has become very close to that budgeted. The small carry-over (10.5%) stems from the fact that the project Ph.D. student was first hired in January (Quarter 2), but was already budgeted in Quarter 1 of Phase 1. We anticipate that this will result in the need for a short no-cost extension at the end of the project. There are no other changes or problems to report.

6 Special Reporting Requirements

None required.

7 Budgetary Information

Table 3 summarizes expenditures for the current phase of the project.

Table 3: Budget Report

	Budget Period 1							
Baseline Reporting	**Q1**		**Q2**		**Q3**		**Q4**	
Quarter	10/1/16 - 12/31/16		1/1/17 - 3/31/17		4/1/17 - 6/30/17		7/1/17 - 9/30/17	
DE-FE0028895	Q1	Cumulative Total	Q2	Cumulative Total	Q3	Cumulative Total	Q4	Cumulative Total
Baseline Cost Plan								
Federal Share	$33,752	$33,752	$29,716	$63,468	$27,810	$91,278	$53,034	$144,312
Non-Federal Share	$12,029	$12,029	$12,029	$24,058	$8,019	$32,077	$4,009	$36,086
Total Planned	$45,781	$45,781	$41,745	$87,526	$35,829	$123,355	$57,043	$180,398
Actual Incurred Cost								
Federal Share	$11,037	$11,037	$22,617	$33,654	$25,957	$ 59,610	$ 69,499	$129,110
Non-Federal Share	$12,029	$12,029	$12,029	$24,058	$8,019	$32,077	$4,009	$36,086
Total Incurred Costs	$23,066	$23,066	$34,646	$57,712	$33,976	$91,687	$73,508	$165,196
Variance								
Federal Share	$-22,715	$-22,715	$-7,099	$-29,814	$-1,853	$-31,668	$16,465	$-15,202
Non-Federal Share	$0	$0	$0	$0	$0	$0	$0	$0
Total Variance	$-22,715	$-22,715	$-7,099	$-29,814	$-1,853	$-31,668	$16,465	$-15,202

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