Characterization of Recoverable Resources from Methane Hydrate Deposits

Progress Report

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Task Progress

Task 1: Project Management Plan (PMP)

Subtask 1.2: PMP for Budget Period (BP) #2: July 2013 – June 2014

Task Duration: 7/1/2013 to 8/1/2013

Completed. The LBNL team worked together with the NETL project manager, and completed the maintenance and update of the project management plan (PMP) of BP #2 within the specified time frame and budget.

Task 2: Code Maintenance, Update and Support

Subtask 2.2: Budget Period (BP) #2: July 2013 – June 2014

Deliverables/Milestones

(1) Completion of uT+H, the new version of the LBNL code for simulation of system behavior in hydrate-bearing geologic systems, and of the corresponding User's Manuals.

Work on this subtask is completed. Activities on code maintenance and update focus on the completion of the TOUGH+HYDRATE Unicode (uT+H), i.e., the most recent version of the code that can be run without any modification on either serial or any multi-processor platform (thus eliminating the need for maintaining two very different versions of code). The Unicode represents the state-of-the-art of computing design architecture. It eliminates the need to maintain and support two very different versions of the code, in addition to providing very significant improvements in execution speeds as they can use more than the single processor to which serial codes limit execution. Even the most basic current computational platforms (i.e., personal computers) have more than one processor, and uT+H can realize very significant speed gains by increasing the number of processors (through a simple user-controlled input) assigned to the computational task of solving a hydrate problem.

The uT+H code is fully functioning, but there is room for improvement. The effort here vastly exceeded the $9K we had allocated for the task. Some of the extra funds were subsidized by another LBNL project with a strong interest in such an activity. Most of the effort in this task in BP #2 focused on enhancing the performance (with an emphasis on execution speed) of uT+H through improvements in the domain decomposition techniques and in the implementation and use of the most modern parallel solvers (already available from other sources, e.g., developed by LLNL, Sandia and NERSC). To that end, the PETC package of parallel solvers was introduced into the uT+H code, replacing the older AZTEC package. The new solvers have distinctive advantages that are in synch with the uT+H code structure and architecture, but also involve time-stepping options that are still being evaluated and are written in C (as opposed to the FORTRAN 2003 language of uT+H), thus requiring more careful integration to ensure interoperability. Additionally, the full implementation of the PETC solvers turned out to be far more demanding and complicated because there was very little support from the developers, and the idiosyncracies of the package had to be deciphered by trial and error.

In addition to the purely numerical aspects, we have added advanced tracking capabilities to all versions of the TOUGH+HYDRATE code. It is now possible to track several properties and conditions in user specified subdomains that can be defined by a list of elements, by geometry (shapes, coordinate limits and dimensions), by a sequence, by columns, or any combination thereof. Additionally, we can track flows across any interface defined by a connection list, by a connection sequence, or by the interface geometry, as well as any combination of such surfaces.

For maximum ease of use and flexibility, we completed the development of a web page application called “pTOUGH-Wimp’ that simplifies substantially the complex process of submitting parallel codes for execution to multi-processor platforms. Thus, a very intricate process has been reduced to a very basic (almost intuitive level), replacing the need for intricate knowledge of parallel system operation by simple choices entered as answers to simple questions in a graphical interface. We are using this package in all our parallel simulations.

We tested the current version of uT+H on several platforms (Macs, clusters to supercomputers), and we are satisfied with the overall performance. We do hope that some funds will be made available in the future for continuous improvement of the code.

Task 3: Support of DOE’s Field Activities and Collaborations

Subtask 3.1: Design support for a DOE-led field test

Subtask 3.1.2. Budget Period: July 2013 – June 2014

Task Duration: 7/1/2013 to 6/30/2014

Deliverables/Milestones

(1) A minimum of one paper on the proposed long-term production test at the current or new potential target sites

(2) Data and information that can be used to design the field test.

Work in this task includes studies focused on the completion and publication of earlier studies on the same subject (concentrating mainly in the PBU L-Pad and Mt. Elbert sites), and on the planning of future potential production field tests at locations not previously considered or investigation of issues that have not been covered in earlier studies. Specific site(s) that were being considered were offshore sites in the Gulf of Mexico (GUM) identified in 2010. These studies focused on the Green Canyon deposits, covered the spectrum of coupled flow and geomechanical system behavior. The paper

> Moridis, G.J., M.T. Reagan, R. Boswell, T. Collett and K. Zhang, *Preliminary Evaluation of the Production Potential of Recently Discovered Hydrate Deposits in the Gulf of Mexico*, Paper OTC 21049, 2010 Offshore Technology Conference, Houston, Texas, May 3-6, 2010.

is a much expanded version of an earlier conference paper (2010 Offshore Technology Conference Paper 21049), and was submitted for publication in the **Journal of Marine and Petroleum Geology**.

Additionally, an analysis of coupled flow, thermal and geomechanical system response during gas production from the PBU L106 site using both vertical and horizontal wells was completed, and was submitted for publication to the SPE Journal under the title:

> Moridis, G.J., M.T. Reagan, H. Anderson-Kuzma, Y. Zhao, K. Boyle, and J. Rector, *Evaluation of the Hydrate Deposit at the PBU L-106 Site, North Slope, Alaska, for a Long-Term Test of Gas Production*

This is a combination of two earlier conference papers (2010 Offshore Technology Conference Paper 944482 and SPE Paper 133601), after a significant revision and addition of new data.

In collaboration with Statoil, we also completed a study of production from a large-scale, extremely heterogeneous reservoir in contact with large aquifers in the Gulf of Mexico using both horizontal and vertical wells. The results of the study were discussed in the paper

> Reagan, M.T., G.J. Moridis, K.L. Boyle, C.M. Freeman, L. Pan, N.D. Keen, and J. Husebo, *Field-Scale Simulation of Production from Oceanic Gas Hydrate Deposits*

which has just been accepted for publication and is currently in press in **Transport in Porous Media**.

Finally, the bulk of the simulations (3D, involving millions of elements and equations) in a study on the effectiveness of slanted wells in the production of gas from highly stratified hydrate deposits have been concluded, and the results were analyzed. Such stratified deposits are among the recent GUM discoveries, and slanted wells are an option that demands evaluation given the relative inefficiency of both vertical and horizontal wells. However, the very limited budget available for this subtask, and the fact that we significantly exceeded the deliverables, did not permit the significant investment in time and effort needed for the preparation and submission of a fourth manuscript. We hope to accomplish the task in the future.

Subtask 3.2: Activities in Support of the Joint U.S.-Korea Gas Hydrate Studies
Subtask 3.2.2. Budget Period: July 2013 – June 2014

Task Duration: 10/1/2013 to 5/31/2014
Deliverables/Milestones

(1) A minimum of one paper on either the design of the planned long-term test of production from offshore Korean deposits, or on the revised evaluation of production from Korean hydrates, accounting for both flow and geomechanical issues.

Activities in this task were completed on schedule, but the work requests by KIGAM far exceeded the budget provided for the task (even after the infusion of another $50K by DOE). LBNL staff are providing support for joint US-Korea studies on gas production from a particular location in the Ulleung Basin of the Korean East Sea. The main component of this study is support for the development of a design for a short-term (14 days long) field test planned for 2014 in the Ulleung Basin. The study included the investigation of the short-term system behavior in the base case (involving laboratory-derived properties and conditions measured at the site), in addition to (1) 5 different bottom-hole pressures, (2) three different depressurization rates, (3) sensitivity analyses to the following parameters: hydrate saturation, porosity, boundary permeability, sand permeability, interlayer permeability, sediment specific heat, sediment thermal conductivity, and anisotropy, and (4) fully-coupled flow and geomechanics study, with (5) analysis of sensitivity to the following parameters: Poisson's ratio of all layers, Young's modulus, cohesion angle. KIGAM requested outputs at the end of every one of the 14 days of the intended test, in addition to results on the long-term performance of the system (over 1500 days, but only for the base case).

The results of the study were presented to KIGAM in March 2014. The paper:

> Moridis, G.J., J. Kim, M. Reagan and S.J. Kim, *System Response During Short- and Long-Term Gas Production from a Gas Hydrate Deposit at the Site of a Planned Field Test in the Ulleung Basin*, Paper OTC 25384, 2014 OTC, May 5-8, Houston, TX.

describes the KIGAM study and was presented to a special session on hydrates during the 2014 Offshore Technology Conference. An expanded version of the paper is currently under review for publication in the SPE Journal of the Society of Petroleum Engineers.

Subtask 3.3: Analysis of the results of the Iġnik Sikumi field test, North Slope, Alaska
Budget Period: July 2013 – June 2014

Task Duration: 9/1/2013 to 4/30/2014
Deliverables/Milestones

(1) *A report on the analysis of the Iġnik Sikumi field test, and a minimum of one paper on the subject (to be submitted for publication in a peer-reviewed journal).*.

Activities in this task were completed. This task involved an analysis of the results of the Iġnik Sikumi field test of gas production from hydrates associated with the Alaskan permafrost. More specifically, work in this subtask did not involve an analysis of the earlier part of the test (which involved N2+CO2 injection), but focused exclusively on

the later phase of the test, which entailed long-term depressurization-induced gas production. This test was conducted in 2012 in collaboration with ConocoPhillips, and resulted in gas production rates that are higher, by an order of magnitude, than flow rates in all earlier field tests (e.g., Mallik tests in 2002, 2007 and 2008).

Work in this subtask included collaborations with other organizations (DOE, National Laboratories, USGS, ConocoPhillips) involved in the design and execution of the field tests, as well as in the analysis of the production results and observations. The analysis was not limited to strictly flow and thermal processes, but also accounted for the geomechanical system response. A two-way coupling between flow and geomechanical processes was involved in the simulations, in an effort to determine the possible effects of the interdependence between flow (porosity and permeability) and geomechanical properties, and whether significant changes in either set of properties occurred during the test (with a corresponding impact in the overall system behavior).

The comparison of production observations/measurements to numerical predictions based on independently obtained data (e.g., media permeability from laboratory tests, hydrate saturation distributions from geophysical surveys, etc.) was completed. The geomechanical component of the study showed minimal subsidence (on the order of a few cm) at the surface and at the top of the hydrate layer, a result generally expected because of the stiffness of the permafrost. The results show a good agreement between simulation results and later-time field observations, after appropriate adjustment of parameters in the course of the "history-matching" process. However, despite initial very encouraging results, the history-matching process that led to a good overall agreement between observations and numerical predictions turned out to be much lengthier and more difficult than expected, necessitating multiple iterations that far exceeded the time and budget allocated to this subtask. This difficulty is assumed to have been caused by the continuation of significant CO_2 and N_2 releases even at later times, a process that, if true, presents significant problems to the entire matching process because the T+H code does not have the capability to describe the behavior of such complex hydrates. Although the study has been completed and a paper on the subject is being prepared, the manuscript had not been completed at the time of the submission of this report. It is expected that completion can take another 30 days, but there hesitation on the part of the contributors to this study to submit it for review because of the possibility of late CO_2 and N_2 releases. We do intend to review the evolution of gas composition over time to address this issue, but this does not appear possible under the restrictions of the current phase of the project.

Other Related Activities

G. Moridis was the organizer of four sessions on gas production from hydrates during the upcoming 2014 Offshore Technology Session (held in Houston, Texas, on May 5-8, 2014), as well as a co-chair of one session. Distinguished members of the gas hydrate community served as co-chairs of the sessions. The number of sessions and papers (28) represented about 10% of the technical program of the entire OTC, and received a very positive response by both the OTC board and the participants. It is noteworthy that the

Japanese participants (who were given a dedicated session) presented for the first time results from their 2013 field study on gas production from hydrate deposits at the Nankai Trough.