Oil & Natural Gas Technology

DOE Award No.: DE-FE0024296

Quarterly Research Performance Progress Report

(Period ending: 09/30/2016)

Methods to Enhance Wellbore Cement Integrity with Microbially-Induced Calcite Precipitation (MICP)

Project Period: October 1, 2014 – September 30, 2018

Submitted by:
Adrienne Phillips

Adrienne Phillips

Digitally signed by Adrienne Phillips
DN: cn=Adrienne Phillips, o=Montana State University, ou=Energy Research Institute, email=adrienne.phillips@biofilm.montana.edu, c=US
Date: 2016.11.04 08:40:27 -06'00'

Montana State University
DUN's Number: 625447982
Energy Research Institute
P.O. Box 172465
Bozeman, MT 59717-2465
adrienne.phillips@biofilm.montana.edu
(406) 994-2119

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

November 4, 2016

Office of Fossil Energy

ACCOMPLISHMENTS

Goal

The goal of this project is to develop improved methods for sealing compromised wellbore cement in leaking gas wells, thereby reducing the risk of unwanted upward gas migration. To achieve this goal an integrated workplan of laboratory testing, simulation modeling and field testing is underway. Laboratory testing and simulation modeling (with assistance from the University of Stuttgart) are being conducted at the Center for Biofilm Engineering (CBE) at Montana State University (MSU) and field testing is being carried out at the 1498 m (4915 foot) deep Alabama Power Company well located at the Gorgas Power plant in Walker County, Alabama (Gorgas #1 well). This project will develop technologies for sealing compromised wellbore cement using the process known as microbially induced calcite precipitation (MICP). The project has two main objectives:

Objective 1: Prepare for and conduct an initial MICP field test aimed at characterizing a region of compromised well cement in the Gorgas well which is suitable for MICP sealing. The location chosen for MICP sealing is the interval of 310.0 -310.9 m (1017-1020 feet) below ground surface (bgs). The first MICP sealing test was completed in April 2016.

Objective 2: After thorough analysis of the results from the first field test, our team will conduct a second MICP test using improved MICP injection methods. The second field test will target compromised wellbore cement located near the underground coal seam at an as of yet undetermined location.

After each test at Gorgas, the following methods will be employed to assess effectiveness of the MICP seal: pressure falloff testing, sustained natural gas flow rate testing at the well head, ultrasonic imaging tool (USIT) logging to assess the cement bond log, and side wall coring. Successful demonstration of improving wellbore integrity and sealing gas leaks from poor cement bond regions will result in a reduction in the pressure falloff, reduction in the sustained gas flow rate at the well head, noticeable differences in the USIT data in the targeted biomineralization regions, and demonstration of MICP byproducts ($CaCO_3$) in the treated regions on side wall cores.

The project milestones are shown below in Table 1. This table was updated to reflect the change in milestone dates per the one year no-cost time extension that went into effect October 1, 2015.

Table 1. Project Milestones

Related Task	Milestone Number	Milestone Title	Planned Completion Date	Revised Completion Date	Verification Method
1.0	1	Update Management Plan	11/30/2014	NA	PMP
1.0	2	Kickoff Meeting	11/06/2014	NA	Presentation
2.1	3	Complete construction and testing of wellbore-cement analog testing system. Expected result is a system which facilitates biomineralization	3/31/2015	NA	Quarterly Report

		sealing in annular spaces representative of field conditions.			
3.2	4	Complete first wellbore cement remediation field test. Expected results include obtaining side wall cores and pressure testing to evaluate the extent of biomineralization sealing.	9/30/2015	9/30/2016	Quarterly Report
4.1	5	Complete analysis of field data from first field test. Expected result is a data set which will enhance the design of the second field test.	3/31/2016	3/31/2017	Quarterly Report
4.1	6	Complete design of injection protocol for second field test.	9/30/2016	9/30/2017	Quarterly Report
5.2	7	Complete second field test. Expected results include obtaining side wall cores and pressure testing to evaluate the extent of biomineralization sealing.	3/31/2017	3/31/2018	Quarterly Report
6.0	8	Complete analysis of laboratory, simulation modeling and field data. The expected result will be a comprehensive evaluation of MICP sealing technology for well cement repair.	9/30/2017	9/30/2018	Quarterly Report

Accomplishments under the goals

Project Planning. During this reporting period, multiple teleconference calls have been conducted including Jim Kirksey of Loudon Technical Services for Schlumberger (SLB), Robin Gerlach, Lee Spangler, Al Cunningham, and Adie Phillips (MSU), and Randy Hiebert of Montana Emergent Technologies (MET). A meeting was held September 7-8, 2016, at MSU with Jim Kirksey, MSU, and MET to discuss the field test results, continuing the mobile operations center design trailer, upcoming characterization work, and the second field demonstration.

April 2016 MICP field test results. As previously reported, the MICP cement channel sealing treatment demonstration was performed in April 2016 over the course of five days where biomineralization fluids and microbial growth media components were delivered to the interval of interest using a delivery bailer method. The experiment was successful and three major results were obtained through the demonstration:

1. Injectivity was significantly reduced after MICP treatment. The injection flow rate had to be decreased as pressure increased to remain below a maximum pressure 81.6 bar (1200

psi) that could have potentially initiated a fracture in the shale formation which was dominant in this interval.

2. A comparison of Ultra Sonic Imager (USIT) logs taken before and after MICP treatment of the target interval indicated a significant increase in the solids content after sealing (Figure 3).

3. Pressure fall-off tests after MICP treatment met the Colorado definition of mechanical integrity for shut in wells which is "less than 10% pressure fall off in 15 minutes".

Summary of Results. These three results offer compelling evidence that the MICP sealing field demonstration at Gorgas resulted in significantly reduced injectivity which corresponded to substantial deposition of precipitated solids along the original flow channel. The MICP treatment also resulted in a sealed cement region which passed the Colorado definition of a mechanical integrity test of "less than 10% pressure fall off in 15 minutes". The positive results have been discussed among MSU, MET, and SLB and the team is in agreement that additional development of the technology (including the addition of a mobile operations center) will advance the technology readiness level of the sealing method. Additional experiments are underway in the laboratory including a large scale radial flow experiment.

Mobile Operations Center Development. Two planning meetings have been held between Montana Emergent Technologies and MSU personnel to discuss the development of the mobile operations center. Several design options were discussed and evaluated. Some of the design considerations evaluated are: the desired characteristics of the mobile operations center; the major functions that the unit needs to serve; and the layout and specific equipment desired. After the design considerations were discussed the technical feasibility including trailer length, weight capacity and construction were addressed. Additional design meetings are required to finalize the desired characteristics, function, and technical feasibility of the mobile operations center.

Characteristics of the mobile operations center

The desired characteristics of the mobile operations center are:

1. Rapidly deployable;
2. Self-contained;
3. Field-ready;
4. Flexible;
5. Suitable for four-season use;
6. Equipped with built-in redundancy; and
7. Safe, i.e. Meet codes and standards.

In order to accommodate these desired characteristics it was important to consider the major functions of the mobile operations center.

Major functions of the mobile operations center

In the mobile operations center, the major desired functions include: (1) operations control and communications; (2) laboratory activities; (3) storage; and (4) pumping (to bailer or downhole). The operations control and communications center is a location in the trailer where command modules via computer control can be used to turn pumps on and off, monitor pressure, download data. Also important is the ability for researchers inside to communicate with personnel outside of the trailer, via a window and/or radio or PA. Thus, windows are planned in multiple sections of the trailer which will also contribute to reduce electricity needs for lighting.

Major laboratory activities will include inoculum/enzyme preparation and media and solution preparation. Additional laboratory activities will include analysis of any samples gathered and use of the required instruments to monitor quality of fluids to be injected. For example, a pH meter will be used to check fluids before they are pumped downhole to make sure the fluids are not inhibitory to ureolysis. The trailer will be equipped with storage such that chemicals can be procured prior to deployment, weighed out and standing ready for mixing in the field. Bringing the quality-checked chemicals along will help minimize time spent on site in preparation for field activities. The portion of the trailer devoted to fluid handling will be located on the side of the trailer so hoses (on reels) can be rolled out to either inject downhole or fill the bailer. Tanks can be used for mixing and fluids can be pumped directly from the tanks outside the trailer. Housing the tanks in the trailer will allow for operations during all four seasons since heating in the trailer will alleviate the risk of freezing.

<u>Layout and specific equipment needed</u>
A draft layout of the mobile operations center is shown in Figure 1. As currently designed, the front of the trailer houses the laboratory section, the middle is the operation and communication center, and the back is the fluid handling section. The mobile operations center is currently considered to be housed in a 28’ long, 8.5’ wide, 8’ tall cargo trailer.

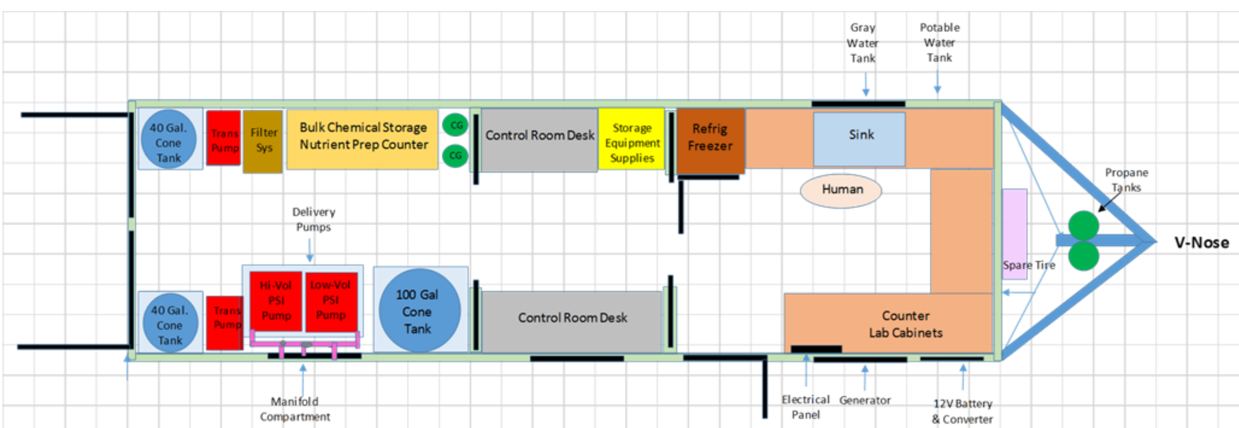

Figure 1. Schematic of design ideas for the development of a mobile operations center.

The laboratory section will be equipped with bench space for sample analysis and instruments during experiments. Instruments and supplies will be stored in cabinets and drawers during transport. The laboratory section will also house a small refrigerator and freezer so microbial inoculum can be transported to the site without special shipping requirements or purchasing dry ice. The control room will be equipped with desk space for computer control modules that will be used to operate the pumps, collect data, and monitor experimental conditions. In the back end of the trailer, the fluid handling equipment including pumps, tanks, valve manifold, and hose reels will be housed. A bench space will be located in the back end of the trailer where chemical storage, weighing, and mixing can be performed. Additional considerations include the placement and type of generator, electrical panel, and power needs. The discussion about the power options is ongoing. Meetings will continue where input from MSU, MET, and SLB will shape the final design options of the mobile operations center.

Opportunities for training and professional development

Dr. Adrienne Phillips led the effort to mobilize and conduct the MICP wellbore sealing field test at the Gorgas facility in April 2016. Eric Troyer, a Chemical and Biological Engineering graduate from MSU (December 2015), worked on the team for the previous three years during his undergraduate education. His undergraduate research efforts included screening sources of chemicals that can promote precipitation economically (he determined urea fertilizer and calcium chloride-based ice melting products worked well). Until May 2016, Eric was employed as a Research Engineer on the team and was instrumental in carrying out the April 2016 field test. He is now pursuing his Ph.D. at the University of California-Berkley utilizing his National Science Foundation Graduate Research Fellowship (NSF GRFP). Drew Norton, a Master's student working on the project attend and presented a poster at a national conference, the Geologic Society of America Annual Meeting held September 25-28, 2016 in Denver, Colorado.

Disseminating results to communities of interest

A press release was launched on the homepage for the Center for Biofilm Engineering which describes the results of the April 2016 MICP field demonstration at Gorgas. http://www.biofilm.montana.edu/news/2016/06/msu-team-reaches-milestone-toward-commercialization-fracture-sealing-process.html. This press release has recently been picked up by the Montana State University News service and the Bozeman Daily Chronicle for further dissemination. (http://www.montana.edu/news/16313/msu-team-shows-biofilm-and-mineral-producing-bacteria-have-potential-for-plugging-oil-and-gas-leaks), and (http://www.bozemandailychronicle.com/news/montana_state_university/msu-research-shows-bacteria-could-plug-oil-and-gas-leaks/article_7d9bef62-08c9-5649-8e96-b24cf77592e9.html).

Planned activities during the next reporting period

The major activity planned for next reporting period is to continue to analyze data from the April 2016 MICP wellbore sealing test at the Gorgas facility, continue the planning and design of the mobile operations center and to summarize a recent radial flow experiment. Additionally, we are planning to perform an injection test to determine the longevity of the mineral seal placed in April.

Products

Conference Presentations

Phillips, AJ, Gerlach, R, Cunningham, AB, Troyer, E, Norton, D, Hiebert, R, Kirksey, J, Rowe, W, Esposito, R, and Spangler, L. "Biomineralization: a strategy to modify permeability in the subsurface". Geologic Society of America Annual Meeting, September 25 2016, Denver, Colorado.

Phillips, AJ, Gerlach, R, Cunningham, AB, Spangler, L. “Methods to Enhance Wellbore Cement Integrity with Microbially-induced Calcite Precipitation (MICP)”. Mastering the Subsurface through Technology Innovation and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting U.S. Department of Energy Fossil Energy and National Energy Technology Laboratory, August 16–18, 2016, Pittsburgh, Pennsylvania.

Posters

Norton, D, Gerlach, R, Eldring, J, Thane, A, Hiebert, R, Cunningham, A, Spangler, L, Phillips, AJ “Visualizing and Quantifying Biomineralization in a Wellbore Analog Reactor”. Geologic Society of America Annual Meeting, September 25 2016, Denver, Colorado.

Norton, D, Gerlach R, Eldring J, Thane A, Hiebert R, Cunningham AB, Spangler L, Phillips, AJ “Visualizing and Quantifying Biomineralization in a Wellbore Analog Reactor”. Montana Biofilm Meeting, July 19, 2016, Bozeman, Montana.

Phillips, AJ, Gerlach, R, Cunningham, AB, Troyer, E, West, C, Norton, D, Hiebert, R, Kirksey, J, Rowe, W, Esposito, R, and Spangler, L. “Biomineralization: A Promising Method to Improve Wellbore Integrity”, Workshop on Natural Gas Storage in Depleted Reservoirs or Aquifers, US DOE National Laboratories, July 12-13, 2016, Broomfield, Colorado.

Other organizations involved as partners

Schlumberger (SLB) (formerly Schlumberger Carbon Services (SCS)). SLB is providing matching support for this project. SCS field workers, led by Jim Kirksey, performed well logging and coring. During this reporting period, Jim Kirksey and others from SLB also participated in the September 2016 data analysis and project planning meeting.

Southern Company (SC). SC is providing matching support for this project. Dr. Richard Esposito of SC, identified and secured the 1493 m (4915 foot) deep well (Gorgas #1 well, Walker County, Alabama) to be used for our MICP field tests.

Montana Emergent Technologies (MET). MET attended meetings where discussion surrounded the current laboratory efforts, the mobile operations center, and the field planning. MET participated at a very high level in performing the April 2016 Gorgas field test.

University of Alabama at Birmingham (UAB). Dr. Peter Walsh is in charge of the UAB Core Testing Laboratory. He will continue conducting core testing activities throughout the duration of this project.

University of Stuttgart. Dr. Rainer Helmig, Director of the Institute for Modelling Hydraulic and Environmental Systems (IWS), and Dr. Johannes Hommel, postdoctoral researcher, are project collaborators at the University of Stuttgart. They along with other colleagues have developed a reactive transport simulation model, referred to herein as the Stuttgart MICP model, that has been integrated with previous laboratory and field research. This model was successfully used to design the Gorgas field test in April 2016.

IMPACT

As reported previously, the results of the April 2016 Gorgas MICP sealing test were positively received by Mr. Jim Kirksey and Mr. Wayne Rowe of Schlumberger. In addition, the success of the experiment has been disseminated through news articles to increase the audience aware of the technology.

Dollar amount of award budget spent in foreign country(ies)

None.

CHANGES/PROBLEMS

As of this reporting period there are no problems to report. As noted above, the project milestone deadlines were revised due to the budget period 1 no cost time extension.

SPECIAL REPORTING REQUIREMENTS

At this time there are no special reporting requirements.

BUDGETARY INFORMATION

Table 2. Cost Plan Status

					NO COST EXTENSION				
Baseline Reporting Quarter	YEAR 1 Start:	10/1/2014	End:	9/30/2015	YEAR 2 Start:	10/1/2013	End:	9/30/2014	Total
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	
Baseline Cost Plan (from SF424A)									
Federal Share	163,575	163,575	163,575	163,575					654,300
									-
Non-Federal Share	31,739	31,739	31,739	31,739					126,956
									-
Total Planned Shares	195,314	195,314	195,314	195,314	-	-	-	-	781,256
									-
Cumulative Shares	195,314	390,628	585,942	781,256					781,256
Actual Incurred Costs									
Federal Share	6,268	19,082	30,237	53,029	83,125	165,886	200,454	48,527	606,607
									-
Non-Federal Share			53,559	51,624	-	12,527	16,622	11,029	145,360
									-
Total Incurred Costs	6,268	19,082	83,796	104,652	83,125	178,413	217,076	59,556	751,968
									-
Cumulative Incurred Costs	6,268	25,350	109,146	213,798	296,923	475,336	692,412	751,968	751,968
Variance									
Federal Share	157,307	144,493	133,338	110,546	(83,125)	(165,886)	(200,454)	(48,527)	47,693
									-
Non-Federal Share	31,739	31,739	(21,820)	(19,885)	-	(12,527)	(16,622)	(11,029)	(18,404)
									-
Total Variance	189,046	176,232	111,518	90,662	(83,125)	(178,413)	(217,076)	(59,556)	29,288
Cumulative Variance	189,046	365,278	476,796	567,458	484,333	305,920	88,844	29,288	29,288
	12/31/2014	3/31/2015	6/30/2015	9/30/2015	12/31/2015	3/31/2016	6/30/2016	9/30/2016	

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, Suite 225
Sugarland, TX 77478

1450 Queen Avenue SW
Albany, OR 97321-2198

2175 University Ave. South
Suite 201
Fairbanks, AK 99709

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