Oil & Natural Gas Technology

DOE Award No.: DE-FE0024296

Quarterly Research Performance Progress Report

(Period ending: 12/31/2015)

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: 2016.01.13 14:21:39 -07'00'

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

January 1, 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 are being conducted at the Center for Biofilm Engineering at Montana State University and field testing will take place 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 which is suitable for MICP sealing. The location for MICP sealing has now been chosen to be in the interval of 310.0 -310.9 m (1017-1020 feet) below ground surface (bgs). The first MICP sealing test is scheduled for late April 2016.

Objective 2: After thorough analysis of the results from the first field test, conduct a second MICP test using improved MICP injection methods. The second field test will target compromised wellbore cement located above the underground coal seam at an as 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, USIT (ultrasonic imaging tool) 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	Project Management Plan
1.0	2	Kickoff Meeting	11/06/2014	NA	Presentation
2.1	3	Complete construction and testing of wellbore-cement analog	3/31/2015	NA	Quarterly Report

		testing system. Expected result is a system which facilitates biomineralization 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	9/30/2017	9/30/2018	Quarterly Report

		evaluation of MICP sealing technology for well cement repair.			

Accomplishments under the goals

Project Planning. During this reporting period, multiple teleconference calls were conducted and included Jim Kirksey (SLB), Robin Gerlach, Lee Spangler, Al Cunningham, and Adie Phillips (MSU). Issues discussed have mainly centered on planning for Jim Kirksey (SLB) to visit the Gorgas well site and conduct additional side wall coring and pump testing during the December 8-11, 2015 field trip to the Gorgas site.

Accomplishments this reporting period. The major activity completed this reporting period was the second round of sidewall coring and cement characterization at the Gorgas well. This field test consisted primarily of drilling three side wall cores at elevations 310.0, 310.3, and 310.9 m (1017, 1018 and 1020 feet) bgs, capturing and analyzing core samples, and then running a pressure-flow test to evaluate the feasibility of sealing flow paths through compromised cement using MICP. A complete description of the field test, which occurred December 8-11, 2015, is given below.

Results from December 8-11, 2015 Gorgas field test

The purpose of this field test was to determine a location downhole in the Gorgas well where the well cement is suitable for sealing using MICP technology. For MICP to be successful, the cement must exhibit flow pathways which allow injected MICP fluids to penetrate and precipitate calcium carbonate. The December 2015 characterization of the Gorgas well bore cement was accomplished by Jim Kirksey, Schlumberger, and Adie Philips, CBE, with assistance from Southern Company and the Alabama Power Company.

Location for side wall coring. The location chosen for side wall coring was determined based on results from the previous field test conducted at Gorgas in May 2015. This test resulted in the cement bond log shown in Figure 1. Careful analysis of this log suggested that cement in the vicinity of 310.0 m (1017 feet) bgs appears to contain cement which is perforated by a significant water flow channel. If this flow channel is continuous, it will allow injected MICP fluids to move upwards (or downwards) through the cement matrix, thereby creating a significant zone over which calcium carbonate sealing can occur.

Field site preparation. On December 7, 2015, equipment was mobilized at the Gorgas well site by Schlumberger. Major field equipment included a workover rig, a water truck, and a wireline truck as shown in Figure 2.

Sidewall coring. The sidewall coring device is shown in Figure 3. The device was lowered via wireline to the elevation chosen for coring then activated. The core bit is intended to drill through the well casing into the cement and further into the surrounding formation, thus extracting an intact core sample of casing, cement, and formation material.

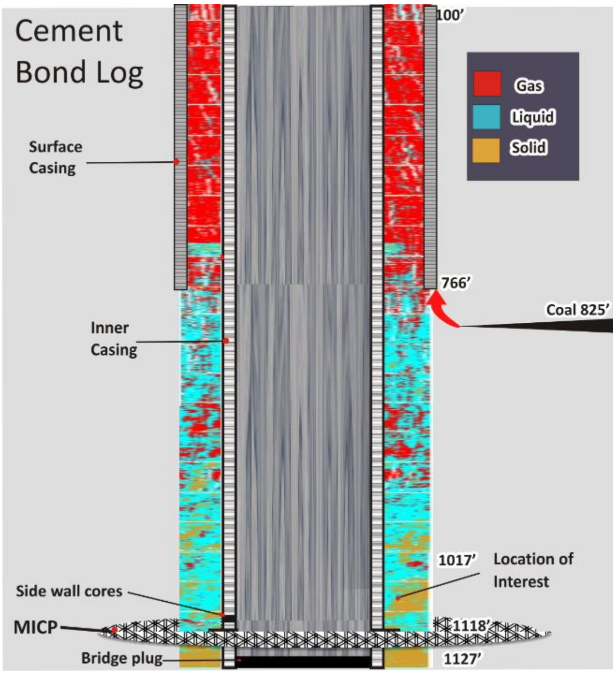

Figure 1. *This cement bond log, obtained in May 2015, suggests that the region near 310.0 m (1017 feet) bgs is favorable for an MICP sealing experiment as it is thought a channel exists in the cement behind the casing. The side wall cores obtained in the December 2015 field test were located at 310.0, 310.3, and 310.9 m (1017, 1018 and 1020 feet) bgs. It should be noted that the April 2014 MICP fracture sealing experiment that was performed as part of the DOE project DE- FE0009599 was performed at 340.8 m (1118 feet) bgs as shown.*

(a)  *(b)* 

Figure 2. ***(****a) Workover rig for installing 7.30 cm (2.875 inch) tubing in well. (b) Wireline for lowering and raising downhole camera, sidewall coring device, and the isolation behind casing scanning tool (IBC).*

(a)  (b) 

Figure 3. *(a) Sidewall coring device which was lowered into well with the wireline. (b) Sidewall coring bit containing extracted core sample.*

Analysis of recovered side wall cores. On December 9, 2015, a sidewall core was successfully recovered for depth 310.0 m (1017 feet) bgs. This core, shown in Figure 4a, consisted of steel casing and good quality cement. It should be noted that a significant fracture transects the cement core, possibly serving as a channel for flow of injected fluids. This core sample did not extend into the surrounding formation. On December 10, 2015, another core was recovered from elevation 310.3 m (1018 feet) bgs. The recovered core, which consisted of steel casing, good quality cement, and dense black shale, is shown in Figure 4b. Later on December 10, 2015, a third core was drilled at elevation 310.9 m (1020 feet) bgs. This time the core bit penetrated the steel casing into a region devoid of cement. This very likely was the channel which was identified in the May 2015 cement bond log. No cement or shale was recovered.

(a)  (b) 

Figure 4. *(a) Sidewall core consisting of steel casing and fractured, good quality cement recovered from elevation 310.0 m (1017 feet) bgs. (b) Sidewall core, consisting of steel casing, cement, and dense shale recovered from elevation 310.3 m (1018 feet) bgs. A third coring at elevation 3120.9 m (1020 feet) bgs showed a void in the cement behind the casing. No cement or shale was recovered.*

Pressure-flow test results. On December 11, 2015, a packer-bridge plug system was installed to isolate the region above and below the location of the three side wall cores. Water was then pumped into the cement region through the sidewall core holes to establish the relationship between pressure and injection flow rate. The target injection flow rate for the planned MICP sealing test was chosen to be 1.89 L/min (0.5 gpm). For this flow rate to be acceptable the injection pressure had to remain below the pressure necessary to fracture the formation (determined in April 2014 to be approximately 81.6 atm (1200 psi) down-hole pressure). The following paragraph is quoted directly from the summary field report by Jim Kirksey of Schlumberger which describes in detail how the pressure-flow test progressed.

Description of pressure-flow test taken directly from Schlumberger field report:

> *"…Started injection at 1.89 L/min (0.5 gpm) Pressure increased steadily to 56.8 atm (835 psi) where it varied between 53.9 atm (793 psi) and 56.1atm (825 psi) for 15.1 L (4.0 gallons) and then started to steadily increase reaching 78.43 atm (1153 psi) after 98.4 L (26 gallons) pumped. Pressure then slowly declined to 64.6 atm (950 psi) after 113.6 L (30 gallons) pumped. Shut down and monitored pressure decline. Down to 34.3 atm (505 psi) after 15 minutes. Discussed next step and made decision to not perforate well with squeeze gun but to continue to inject. Resumed injection at 2.64 L/min (0.7 gpm) with pressure starting at 64.21 atm (944 psi) and then slowly declining to 57.8-61.2 atm (850-900 psi). Pressure would vary by 3.4-4.0 1atm (50-60 psi). Pumped total of 469 L (124 gallons). Final injection pressure 58.7 atm (863 psi). Shut down pump. Shut down pressure 49.7 atm (731 psi), @ 5 minutes 47.1 atm (692.5 psi), @ 10 minutes 46.1 atm (677 psi), @ 15 minutes 45.2 atm (664.5 psi), @ 20 minutes 44.3 atm (652 psi), @ 225 minutes 43.7 atm (642 psi), and @ 30 minutes 43.1 atm (634 psi). Bled off pressure and flow back declined immediately to a trickle. Closed well in and pressure would slowly increase. Unset packer and tripped out of hole laying down tubing and rigged down workover rig. Released all rental equipment. This part of project finished by establishing a flow rate through the channels in the cement".*

Summary analysis. Observations from the pressure flow test suggest that the constant flow rates (first 1.89 L/min then 2.64 L/min (0.5 gpm then 0.7 gpm)) resulted in several episodes of pressure first increasing to a maximum of 78.43 atm (1153 psi), then decreasing. This behavior suggests that the injection flow was gradually breaking through to establish flow channels which are more connected (and possibly wider) than initial channels. The last pumping episode, which involved pumping a total of 469 L (124 gallons) at 2.64 L/min (0.7 gpm) (177 minutes in duration), provides a very favorable indication that the planned injection of MICP fluids to achieve cement sealing can be accomplished. The previous formation fracture sealing test at Gorgas in April 2014 resulted in MICP sealing of a single pancake fracture in the surrounding sandstone over a three day period. The design injection flow rate for this test was 1.89 L/min (0.5 gpm) and the injection pressures achieved during the test were very similar to those observed for the December 2015 injection test.

Based on these data and observations, it is the collective opinion of CBE researchers and Schlumberger that the well cement in the 310.0 – 310.9 m (1017-1020 feet) bgs interval offers a good candidate for sealing with MICP technology. Accordingly, planning will commence to conduct the MICP sealing test at Gorgas very likely in the latter part of April 2016.

Opportunities for training and professional development

Dr. Adrienne Phillips was a Ph.D. student in Environmental Engineering when this proposal was written in June 2014. She was subsequently hired as an Assistant Professor in Environmental Engineering at Montana State University. As a Co-PI on this project and with years of biomineralization laboratory and field project management, she was the likely candidate to step in as a temporary PI during Al Cunningham's five month break in service during July – November, 2015. Therefore, this project is affording Adie the opportunity for professional development by serving as a Principal Investigator. It is the opinion of Lee Spangler, Project Director and Al Cunningham that, given Adie's high level of accomplishment during fall 2015, together with her leadership in organizing and conducting the successful December 2015 field test, it is clear that she is eminently qualified and will continue serving as project PI on a permanent basis. Dr. Cunningham has now completed his mandatory five month service break, has re-joined the project, and will continue to serve as a co-principal investigator.

Disseminating results to communities of interest

Project results will be disseminated in a timely fashion through publications, conference participation, etc. During this reporting period, a manuscript entitled "Fracture Sealing with Microbially-Induced Calcium Carbonate Precipitation: A Field Study" has been submitted to Environmental Science and Technology (ES&T). The following poster presentation was made by Dr. Robin Gerlach at the American Society of Microbiology Biofilms Conference in October 2015. Gerlach, R, Cunningham, A, Phillips, AJ, Hiebert, R, Lauchnor, E, Mitchell, AC and Spangler, L "Biofilm-Mediated Mineral Precipitation Technology – from the Microscale to the Field-Scale" October 2015, 7th American Society of Microbiology Biofilms Conference, Chicago, IL.

Planned activities during the next reporting period

During the next reporting period our project team will continue MICP seal testing on the 10.16 cm (4 inch) well-bore cement system and the composite fracture fixture reactor. This testing will focus on development and optimization of MICP injection protocols suitable for developing MICP sealing in de-bonded well cement at the Gorgas well. We will also continue analysis of the side wall coring materials and well bore fluids retrieved from the December 7-11, 2015 field test at Gorgas. We will continue the project planning process by way of teleconferences with SCS, SC, UAB, and Stuttgart collaborators. Our project team will participate in the Web-based Quarterly Reporting conference which at the time of this report has not yet been scheduled.

Products

Adrienne J. Phillips, Alfred B. Cunningham, Robin Gerlach, Randy Hiebert, Chiachi Hwang, Bart Lomans, Joseph Westrich, Jim Kirksey, Richard Esposito, Lee Spangler. Fracture Sealing with Microbially-Induced Calcium Carbonate Precipitation: A Field Study, Environmental Science and Technology (ES&T), Submitted November 2015, In revision.

Gerlach, R., Cunningham, A, Phillips, AJ, Hiebert, R, Lauchnor, E, Mitchell, AC and Spangler, L Biofilm-Mediated Mineral Precipitation Technology – from the Microscale to the Field-Scale, 7th American Society of Microbiology Biofilms Conference, October 2015, Poster. Chicago, IL

Other organizations involved as partners

Schlumberger (SLB) (formerly Schlumberger Carbon Services). SLB is providing matching support for this project. SLB field workers, led by Jim Kirksey, will help identify and characterize the test locations in the Gorgas well, perform the packer initialization, injection of biomineralization fluids, pre- and post-experiment pressure tests, and well logging and coring. During this reporting period, Jim Kirksey and others from SLB performed the field work described above and conducted analysis of the side wall coring and logging at the Gorgas well.

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

University of Alabama at Birmingham (UAB). Dr. Peter Walsh is in charge of the UAB Core Testing Laboratory. He will be 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 Johannes Hommel, Ph.D. Student, 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 help design the Gorgas field test in April 2014, and will be used again for the design of both laboratory field tests for the current project.

IMPACT

While too soon to evaluate all of the direct impacts of this project, one positive impact is a recently awarded funding announcement. The proposal was recently funded by DOE in response to DE-FOA-0001240, AOI 3 “Advanced Materials and Methods for Mitigating Wellbore Leaks”. The proposal is entitled “Wellbore Leakage Mitigation using Advanced Mineral Precipitation Strategies” where we seek to expand the temperature and depth of the current microbially based solutions with enzymatic or other mineral precipitation strategies.

Impact will be addressed in future reports as appropriate.

Dollar amount of award budget spent in foreign country(ies)
No project funds were spent in foreign countries this reporting period.

CHANGES/PROBLEMS

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

SPECIAL REPORTING REQUIREMENTS

At this time there are no special reporting requirements.

BUDGETARY INFORMATION

Table 2. Cost Plan Status

Baseline Reporting Quarter	YEAR 1 Start:	10/1/2014	End:	9/30/2015	YEAR 2 Start:	10/1/2015	End:	9/30/2016	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				191,740
									-
Non-Federal Share			53,559	51,624	-				105,182
									-
Total Incurred Costs	6,268	19,082	83,796	104,652	83,125	-	-	-	296,923
									-
Cumulative Incurred Costs	6,268	25,350	109,146	213,798	296,923				296,923
Variance									
Federal Share	157,307	144,493	133,338	110,546	(83,125)	-	-	-	462,560
									-
Non-Federal Share	31,739	31,739	(21,820)	(19,885)	-	-	-	-	21,774
									-
Total Variance	189,046	176,232	111,518	90,662	(83,125)	-	-	-	484,333
Cumulative Variance	189,046	365,278	476,796	567,458	(296,923)	-	-	-	484,333
	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

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681