Oil & Natural Gas Technology

DOE Award No.: DE-FE0024296

Quarterly Research Performance Progress Report

(Period ending: 3/31/2015)

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

Project Period: October 1, 2014 – September 30, 2017

Submitted by:
Al Cunningham

Al Cunningham Digitally signed by Al Cunningham
DN: cn=Al Cunningham, o=Montana State University, ou=Center for Biofilm Engineering, email=al_c@biofilm.montana.edu, c=US
Date: 2015.04.23 11:11:48 -06'00'

Montana State University
DUN's Number: 625447982
Energy Research Institute
P.O. Box 172465
Bozeman, MT 59717-2465
al_c@erc.montana.edu
(406) 994-6109

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

April 23, 2015

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') 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 sealing a poor well cement bond in the Gorgas well approximately located 820 feet (249 meters) below ground surface (bgs).

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 approximately 960 feet (293 meters) bgs at Gorgas.

Note. *The exact elevations of the planned field tests at Gorgas well (i.e. 820 and 960 feet bgs) are currently under review. The final elevations may be altered depending on results from the side wall coring test currently scheduled for early in April 2015, as discussed below.*

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.

Table 1. Project Milestones

Related Task	Milestone Number	Milestone Title	Planned Completion Date	Actual Completion Date	Verification Method
1.0	1	Update Management Plan	11/30/2014	PMP was approved 12/01/2014	Project Management Plan
1.0	2	Kickoff Meeting	11/06/2014	Kickoff Meeting was	Presentation

				Held 11/06/2014	
2.1	3	Complete construction and testing of wellbore-cement analog testing system. Expected result is a system which facilitates biomineralization sealing in annular spaces representative of field conditions.	3/31/2015	March 31, 2015	Quarterly Report
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		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		Quarterly Report
4.1	6	Complete design of injection protocol for second field test.	9/30/2016		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		Quarterly Report
6.0	8	Complete analysis of laboratory, simulation modeling	9/30/2017		Quarterly Report

		and field data. The expected result will be a comprehensive evaluation of MICP sealing technology for well cement repair.			

Accomplishments under the goals
Major activities this reporting period include: (1) successful completion of the Kickoff Meeting held by teleconference November 6, 2014 (Milestone 2 has been completed); (2) submission of Project Management Plan (PMP) which was approved December 1, 2014 (Milestone 1 has been completed); (3) completion of a Project Planning Meeting involving Montana State University (MSU), Schlumberger Carbon Services (SCS), Southern Company (SC), and University of Alabama at Birmingham (UAB), December 16-19 in Birmingham Alabama; and (4) initiating development of wellbore cement analog testing system.

Project Planning Meeting. A project planning meeting was held December 16-19 in Birmingham, Alabama. In attendance were Al Cunningham, Lee Spangler, and Adie Phillips (MSU), Jim Kirksey and Bob Butsch (SCS), Richard Esposito (SC), and Peter Walsh (UAB). Discussion topics included review of the cement bond logs for the Gorgas well and scheduling field work to obtain side wall cores from multiple elevations in the Gorgas well.

Review of cement bond log at Gorgas. Analysis of the Gorgas well cement bond logs revealed the presence of multiple locations where the cement layer outside the well casing appears to be compromised thereby creating voids in the cement which can be occupied by either brine (formation water) or gas (methane). As the result of discussions the project team identified at least four and possibly five potential locations where cement debonding is significant enough to conduct sealing repair using MICP technology. This discussion will continue by way of a teleconference call scheduled for January 14, 2015. During this call the list of possible target sites for MICP field testing will be finalized.

Obtaining sidewall cores from Gorgas well. The next step will be to go to the Gorgas well site (likely in early April 2015) and extract side wall cores from each potential location of interest. These cores will be drilled through the well casing to extract a one inch diameter plug of well cement along with a few inches of outside formation material. After examining these side wall cores, the project team will have a much better idea of the exact geometry of fractures and void space within the wellbore cement at each location. From this information the first MICP field test location will be chosen.

Development of wellbore cement analog testing system. The preliminary design process for the laboratory wellbore cement analog system has been initiated. We have begun construction of multiple 1 inch (2.54 cm) core plugs which will replicate various types of well cement debonding. Examples of these cores are shown in Figure 1 which shows cores with a designed annular space between well casing steel and cement and cement and formation sandstone. These annuli will be varied in size to represent fractures and debonding spacing of different aperture size.

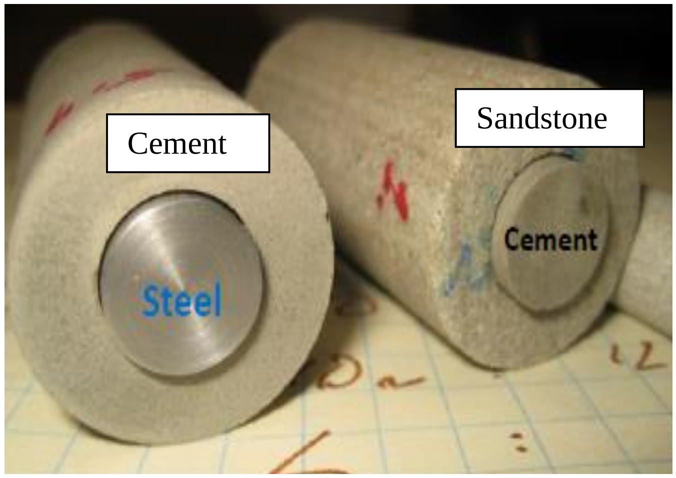

Figure 1. *Well casing/cement and cement/formation material analogs.*

These core plugs will be tested by injecting biomineralization fluids into the annuli using the test system shown in Figure 2. This system will allow for rapid screening of various microbially induced calcite precipitation (MICP) injection protocols. Effectiveness of MICP seals will be evaluated by measuring the change in permeability through the annuli before and after biomineralization.

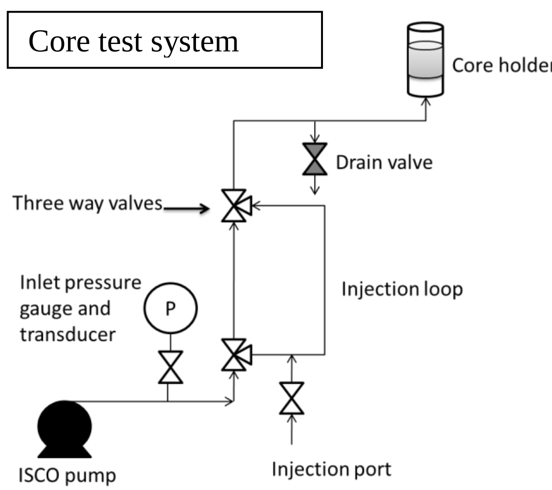

Figure 2. *Test system for developing MICP seal in 1 inch (2.54 cm) diameter cores.*

This system will likely be redesigned after reviewing the results from side wall core testing from the Gorgas well.

Experimental Procedure.

The purpose of this experiment was to assess the ability of microbially-induced calcite precipitation (MICP) to reduce permeability in a defined 100 µm gap in a cement casing analog system. A cement core cylinder was constructed with a Class H oil field well cement with a steel rod placed in the center of the core to mimic a cement/casing interface. A thin piece of metal stripping was slid between the rod and the cement core outer cylinder to hold the rod in place and create a constant gap (100 µm) (Figure 3).

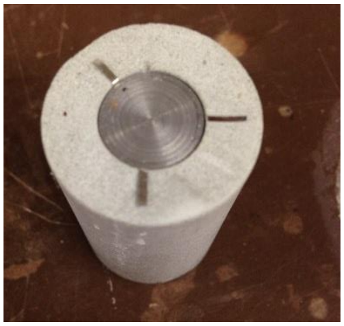

Figure 3. *Cement core cylinder with steel rod placed in the center and thin metal stripping used to center and hold the rod in place and create a 100 µm gap between the rod and cement cylinder.*

An initial permeability of the gap was found before innoculation of the core by recording the pressure at no flow (baseline pressure readout), 0.04, 0.08, 0.16, 0.32 and 0.64 ml/min CMM- solution was the solution used for the initial permeability measurements. An initial permeability was calculated (Figure 4).

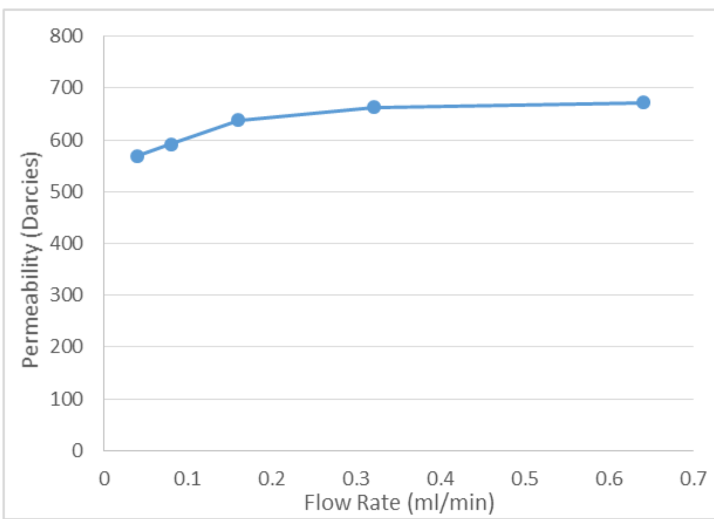

Figure 4. *The initial permeability of the gap between the cement core and the rod was estimated to average 630 Darcies.*

After the baseline initial permeabilty was calculated, the core was inoculated with a *S. pasturii* culture (adjusted to optical density of 0.4, approximately $1x10^8$ cfu/ml). An attachment period of three hours and forty minutes was allowed before a two hour CMM- growth solution was injected to promote biofilm formation. The injected solution was then swtiched to CMM+ which was injected for the rest of the experiment (223 total hours).

Experimental Results.
Over the course of the 223 hour experiment, the permeability of the gap was reduced by seven orders of magnitude (Figure 5).

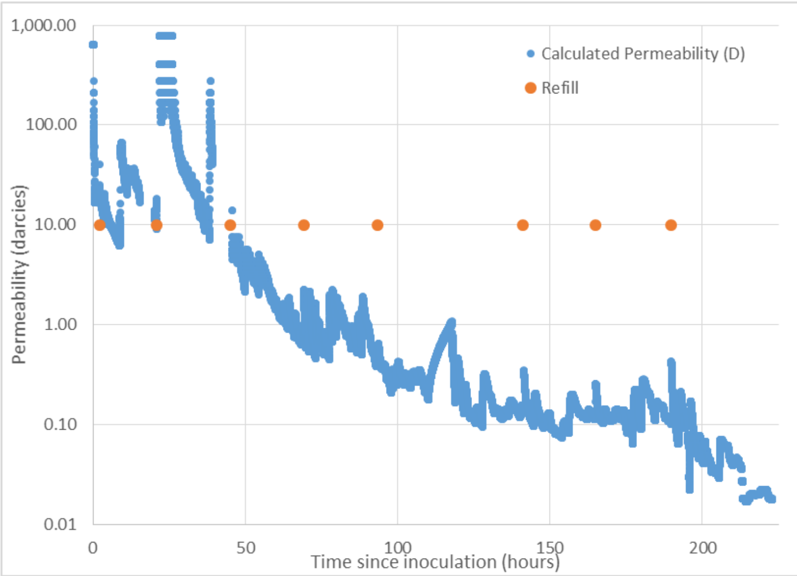

Figure 5. *The permeability of the gap between the cement core and the rod decreased from approximately 630 Darcies before inoculation to 0.02 Darcies after the 223 hour treatment to promote MICP in the gap.*

This is an excellent result considering the goal of achieving at least a three order of magnitude reduction in permeability for wellbore cement integrity enhancement with Microbially-Induced Calcite Precipitation (MICP). Additional experimental results using this system are planned for the next reporting period.

Larger scale well-bore cement analog testing system. The 2.54 cm (one-inch) diameter test system described above has been used to help design a larger well-bore cement analog system capable of simulating actual field conditions at the Gorgas Alabama test site. This larger system has very recently been constructed. The system consists of a 4 inch (10.16 cm) diameter outside casing and a 2.5 inch (6.35 cm) diameter inner PVC delivery pipe. This results in a 0.44 inch (1.18 cm) gap into which well cement can be placed. Flow of biomineralization fluids from the inner PVC pipe into the cement region is accomplished via 4 x 5/16 inch (0.794 cm) diameter injection ports. The system appears to be adequate for forthcoming experimental needs however it can be easily modified if needed. The columns are 1.0 foot (30.4 cm) in height.

Opportunities for training and professional development

Dr. Adrienne Phillips was a PhD student in Environmental Engineering when this proposal was written in June 2014. Adie was subsequently hired as an Assistant Professor in Environmental Engineering at Montana State University. This project is affording Adie the opportunity for professional development by serving as a co-principal investigator and taking responsibility for overseeing the laboratory testing and field demonstration activities.

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" is being prepared for submission to Environmental Science and Technology (ES&T).

Planed activities during the next reporting period.

During the next reporting period our project team will continue MICP seal testing one the 1-inch (2.54 cm) core analogs described above. Also testing will continue using the 4 inch (10.16 cm) well-bore cement system as soon as results from side wall coring at the Gorgas site are available. This testing will facilitate development of MICP injection protocol suitable for developing MICP sealing in de-bonded well cement. 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 scheduled for April 15, 2015.

PRODUCTS

There are no products to report this quarter.

Other organizations involved as partners

Schlumberger Carbon Services (SCS). SCS is providing matching support for this project. SCS field workers, let by Jim Kirksey, will help identify and characterize the test locations in the Gorgas well, perform the packer initialization, well perforation, injection of biomineralization fluids, pre- and post-experiment pressure tests and well logging and coring. During this reporting period Jim Kirksey and others from SCS participated in the Project Planning Meeting held in Birmingham Alabama. SCS will conduct the side wall coring at Gorgas during April 2015.

Southern Company (SC). SC is providing matching support for this project. Dr. Richard Esposito of SC, together with SCS, 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. During this reporting period Dr. Esposito attended the Project Planning Meeting in Birmingham Alabama.

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. Dr. Walsh also attended the December Project Planning meeting in Birmingham, Alabama.

University of Stuttgart. Dr. Rainer Helmig, Director of the Institute for Modelling Hydraulic and Environmental Systems (IWS), and Johannes Hommel, PhD 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. During this reporting period Drs Cunningham, Phillips and Gerlach have had several conversations with Johannes Hommel regarding progress in model development.

IMPACT

It is too soon to evaluate the impacts of this project. 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 changes or anticipated problem to report.

SPECIAL REPORTING REQUIREMENTS
At this time there are no special reporting requirements.

BUDGETARY INFORMATION

Table 2. Cost Status Report

Baseline Reporting Quarter	YEAR 1 Start:	10/1/2014	End:	9/30/2015
	Q1	Q2	Q3	Q4
Baseline Cost Plan (from SF424A)				
Federal Share	163,575	163,575	163,575	163,575
Non-Federal Share	31,739	31,739	31,739	31,739
Total Planned Shares	195,314	195,314	195,314	195,314
Cumulative Shares	195,314	390,628	585,942	781,256
Actual Incurred Costs				
Federal Share	6,268	19,082		
Non-Federal Share				
Total Incurred Costs	6,268	19,082	-	-
Cumulative Incurred Costs	6,268	25,350	25,350	25,350
Variance				
Federal Share	157,307	144,493	163,575	163,575
Non-Federal Share	31,739	31,739	31,739	31,739
Total Variance	189,046	176,232	195,314	195,314
Cumulative Variance	189,046	365,278	560,592	755,906

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