Oil & Natural Gas Technology

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Quarterly Research Performance Progress Report

(Period ending: 06/30/2015)

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

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

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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	3/31/2015	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 completed through 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 (SLB), Southern Company (SC), and University of Alabama at Birmingham (UAB), December 16-19 in Birmingham, Alabama. 4) Completing development of wellbore cement analog testing system.

Project Planning. During this reporting multiple teleconference calls have been conducted including Jim Kirksey (SLB), Al Cunningham, Lee Spangler, and Adie Phillips (MSU). Issues discussed have mainly centered on planning for Jim Kirksey (SLB) to visit the Gorgas well site and conduct side wall coring and isolation scanning. Discussions also included planning the submission of a proposal related to this project. The proposal has been recently submitted 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".*

Obtaining sidewall cores from Gorgas well. In late May, Jim Kirksey of SLB visited the Gorgas well and conducted sidewall coring and additional well logging (isolation scanning). The isolation scanning is currently being processed and will be available soon. The side wall coring was successful in recovering two cement core plugs depths of 1112 feet (340 m) below ground surface (bgs) and 1108 feet (337 m) bgs. Two other coring attempts at higher elevations were unsuccessful at obtaining cement core. The cores are presently being analyzed at our MSU laboratories. When the core analysis and isolation scanning is completed 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. As previously, reported the preliminary design process for the laboratory wellbore cement analog system has been initiated and data are being collected. We have constructed 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.

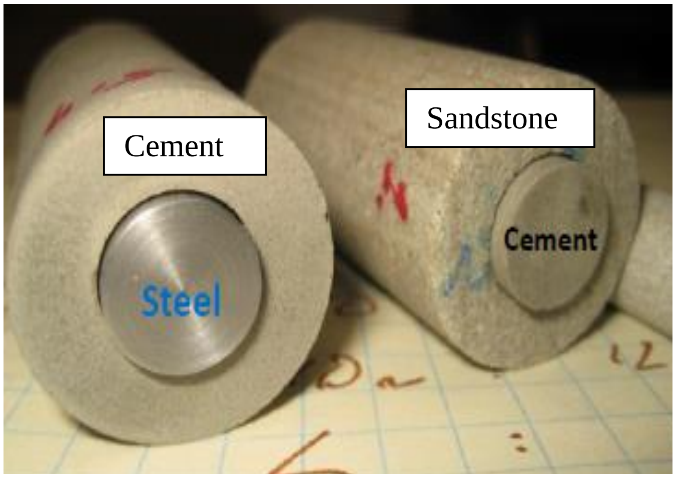


Figure 1. *Well casing/cement and cement/formation material analogs.*

These core plugs are being 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.

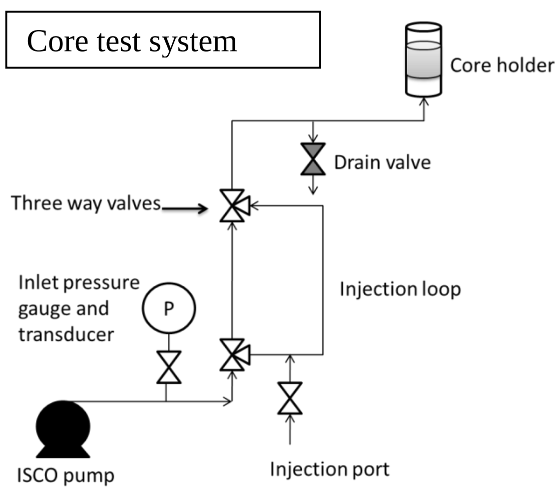


Figure 2*. Test system for developing MICP seal in 1 inch (2.54 cm) diameter cores.*

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 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).

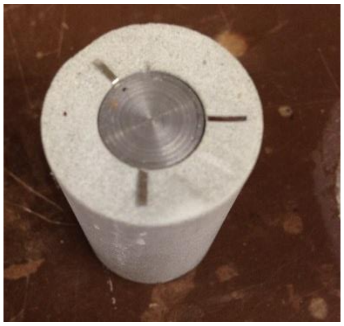


Figure 3. *Cement core cylinder with steel rod placed in the center and thin metal stripping used to center and hold the rod in place and create a 100 µm gap between the rod and cement cylinder.*

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).

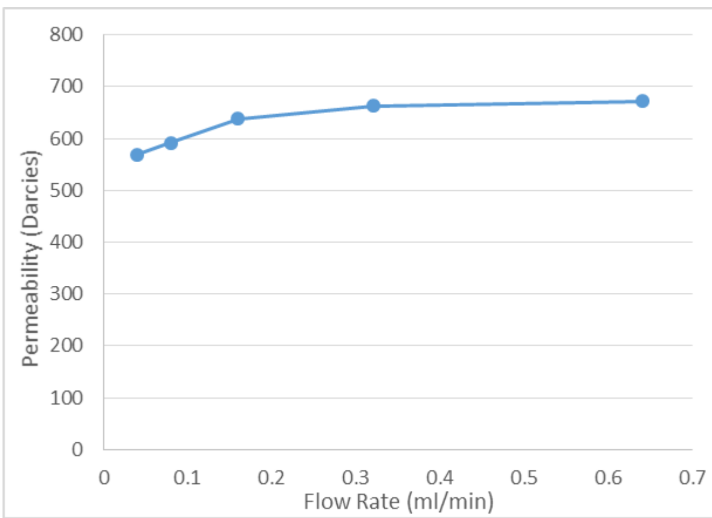


Figure 4. *The initial permeability of the gap between the cement core and the rod was estimated to average 630 Darcies.*

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).

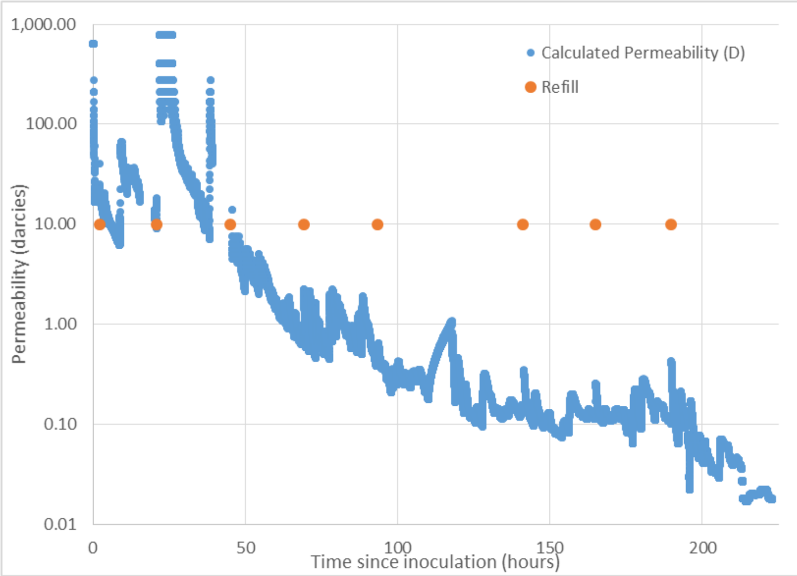
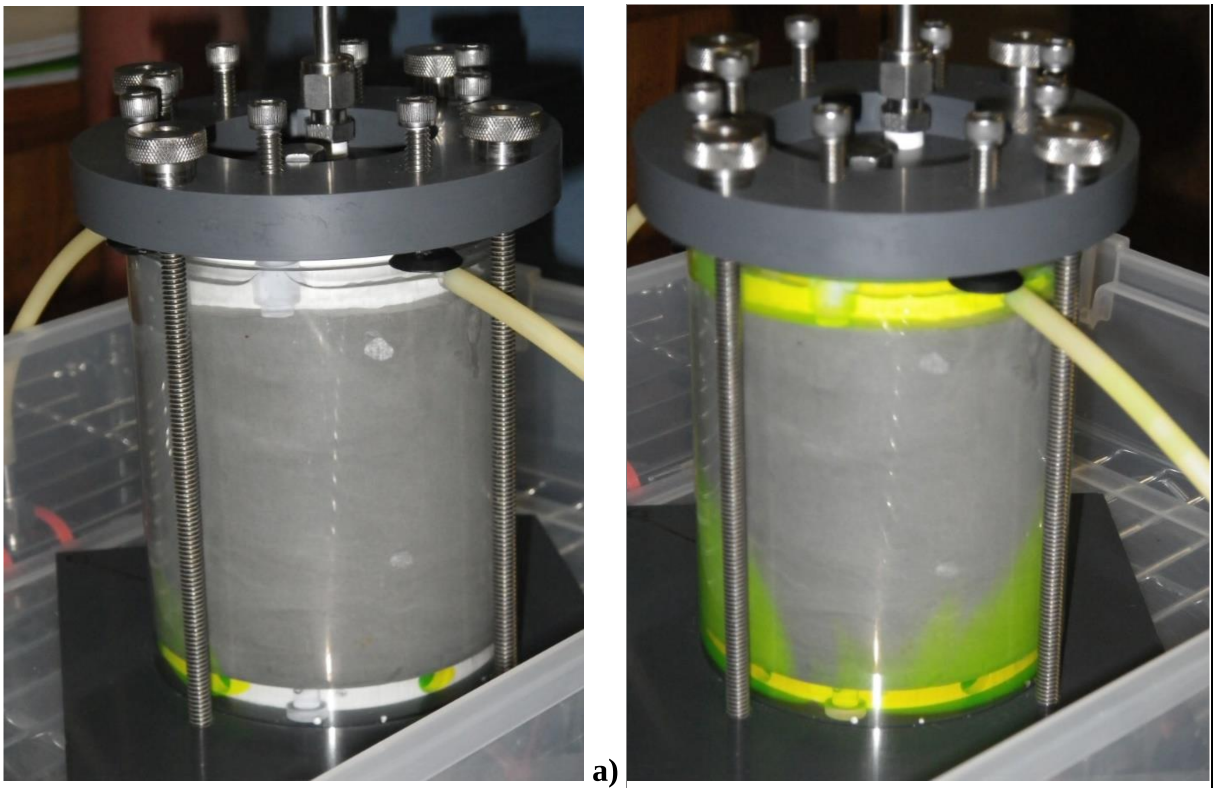


Figure 5. *The permeability of the gap between the cement core and the rod decreased from approximately 630 Darcies before inoculation to 0.02 Darcies after the 223 hour treatment to promote MICP in the gap.*

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 in a well with surface casing. 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 is adequate for forthcoming experimental needs; however, it can be easily modified if needed. The columns are 1.0 foot (30.4 cm) in height. The wellbore cement analog system is shown in Figure 6. This system represents successful completion of **Milestone #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*".



a) b)

Figure 6. *Wellbore-cement analog system composed of two annular PVC conduits with a 0.44 inch (1.18 cm) gap filed with cement. Cement can be fractured if necessary. a) shows cement –filed system at the beginning of a dye tracer injection, b) shows the progression of the dye 5 minutes after injection.*

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). Dr. Phillips will present a paper entitled *"Biological influences in the subsurface: A method to seal fractures and reduce permeability with microbially-induced calcite precipitation"* at the ARMA 15 (American Rock Mechanics/Geomechanics Symposium held in San Francisco, CA, 28 June –July 1, 2015

Planed activities during the next reporting period.

During the next reporting period our project team will continue MICP seal testing on 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. The side wall coring at Gorgas has very recently been completed and analysis of results will take place during the next reporting period. 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 July 28, 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, led 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 has very recently conducted side wall coring and logging at the Gorgas well. Core samples and logs are presently being analyzed.

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 was present during the sidewall coring and logging at the Gorgas well.

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 Johannes Hommel is visiting our laboratories at MSU.

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 Plan Status

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	30,237	
Non-Federal Share			53,559	
Total Incurred Costs	6,268	19,082	83,796	-
Cumulative Incurred Costs	6,268	25,350	109,146	109,146
Variance				
Federal Share	157,307	144,493	133,338	163,575
Non-Federal Share	31,739	31,739	(21,820)	31,739
Total Variance	189,046	176,232	111,518	195,314
Cumulative Variance	189,046	365,278	476,796	672,110

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