Oil & Natural Gas Technology

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Quarterly Research Performance Progress Report

(Period ending: 06/30/2016)

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

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

Submitted by:
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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 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 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	Project Management Plan
1.0	2	Kickoff Meeting	11/06/2014	NA	Presentation
2.1	3	Complete construction and	3/31/2015	NA	Quarterly Report

		testing of wellbore-cement analog 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	9/30/2017	9/30/2018	Quarterly Report

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

Accomplishments under the goals

Project Planning
During this reporting multiple teleconference calls have been conducted including Jim Kirksey of Schlumberger (SLB), Robin Gerlach, Lee Spangler, Al Cunningham and Adie Phillips (MSU), and Randy Hiebert of Montana Emergent Technologies (MET). Issues discussed have mainly centered on planning for our team to visit the Gorgas well site April 11-20, 2016, to conduct the wellbore cement remediation test. After the test was successfully completed additional teleconferences have been held to discuss and process the field test results.

April 2016 Gorgas Field Test Description

December 2015 well characterization. Sidewall coring and pressure testing were carried out at the Gorgas well in December 2015 as reported in our previous quarterly report. Based on data and observations from the December 2015 field work, it was the collective opinion of CBE researchers and SLB that the well cement in the 310.0 – 310.9 m (1017-1020 feet) bgs interval offered a good candidate for sealing with MICP technology. Accordingly, in April 2016 we conducted the MICP sealing test at this interval (see Figure 1).

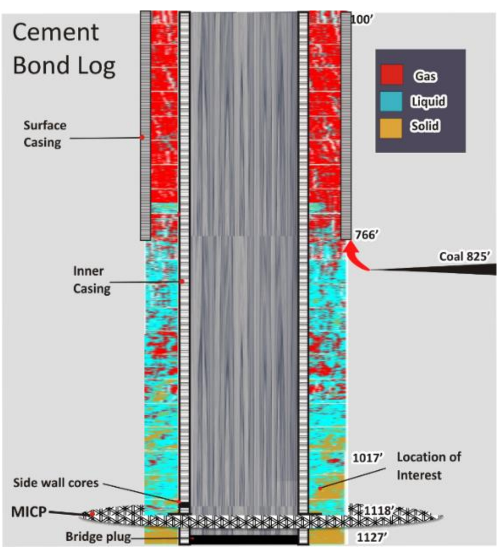

Figure 1. *Schematic showing the cement bond log for the Gorgas well based on December 2015 imaging. The target zone for the April 2016 MICP cement sealing test was the interval 310.0 – 310.9 m (1017-1020 feet) bgs as shown above.*

April 2016 MICP field test results. During the week of April 11, 2016, MSU, MET and SLB moved on-site, received rental equipment and chemicals, and began cultivating microbes.

Pumps, surface tubing, sampling equipment, mobile chemical testing laboratory, and the microbial laboratory were all set up as SLB mobilized equipment including the Slickline truck and rig crew. The MICP channel treatment experiment was performed 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 observed over the course of the experiment:

1. Injectivity was significantly reduced from 0.29 cubic meters per hour (m^3/h) (1.28 gallons per minute (gpm)) to less than 0.011 m^3/h (0.05 gpm) after MICP treatment. Flow rate was decreased as pressure increased to remain below a maximum pressure 81.6 bar (1200 psi) that could initiate a fracture in the shale formation which was dominant in this interval. Data are shown in Figure 2.

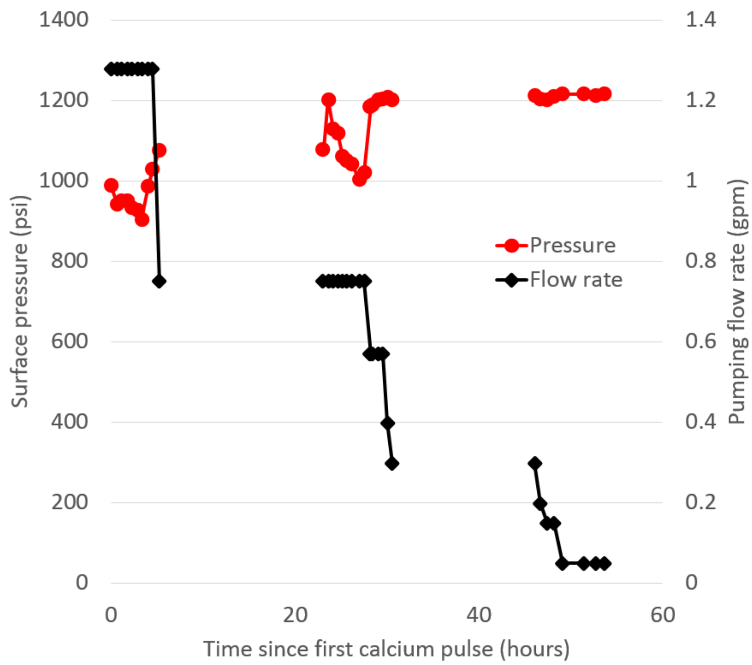

Figure 2. *Pressure increase corresponding to (decreasing) injection flow rate over time during MICP sealing test. Injection was terminated when the formation pressure reached 81.6 bar (1200 psi), which was considered the fracture initiation pressure for the shale formation. The corresponding injection flow rate was less than 0.011* m^3/h *(0.05 gpm).*

2. Significant increase was observed in the solids content in the compromised cement region after sealing from comparison of USIT logs taken before and after MICP sealing of the target interval (Figure 3).

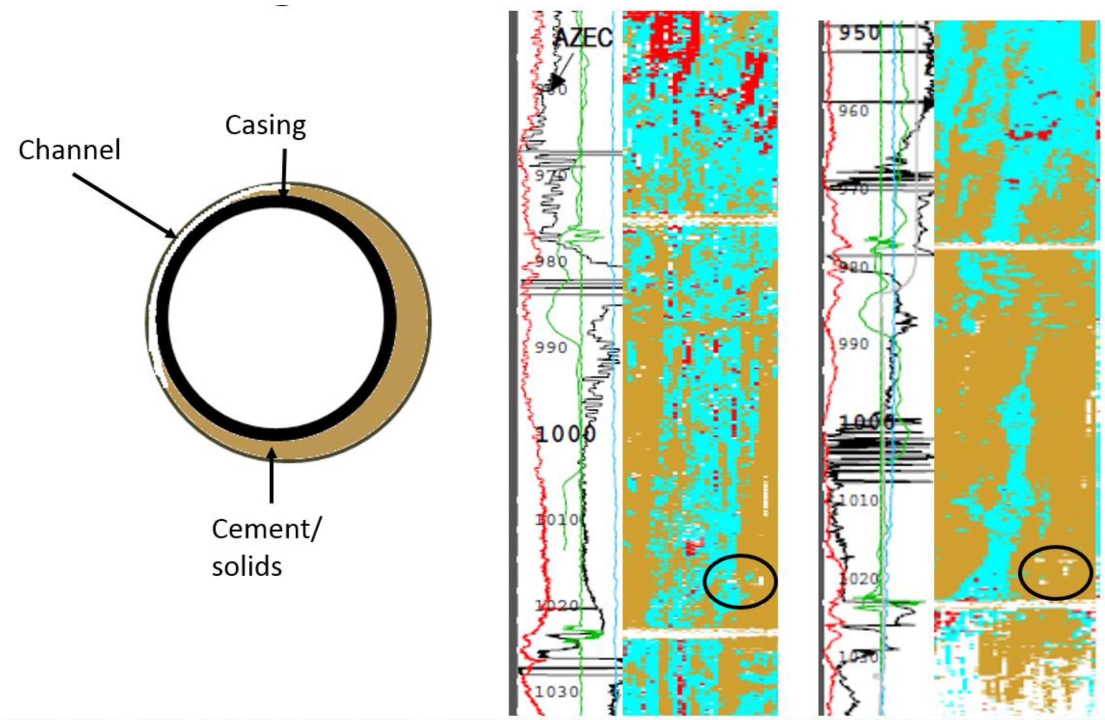

***Figure 3**. Cement bond log scanned with the Schlumberger USIT from 292.60-316.98 meters (m) (960-1040 feet) below ground surface. Left panel shows the log scanned December 2015 after side wall cores were drilled at 310.0, 310.27, 310.57 meters (m) (1017, 1018, 1019 feet) bgs (white circles inside black ovals indicate location of core points). Right panel shows the log scanned after MICP treatment in April 2016. Red=gas, blue=liquid, tan=solids detected in the near wellbore between the casing and the formation. MICP sealing resulted in a substantial increase in solid material in the 40 foot interval above the side wall core injection points. Note that at elevation 990 the solid material completely surrounds the circumference of the casing without visible voids. The diagram to the left of the USIT logs shows the likely plan view configuration of the original flow channel at the 310.0-310.57 meter (1017-1019) foot elevation prior to MICP sealing.*

3. Pressure fall-off tests after MICP treatment met a definition of a Mechanical Integrity Test (MIT) for shut in wells which is “less than 10% pressure fall off in 15 minutes”. On the final day a series of pressure falloff tests were performed. The well was pressured to 20.4 and 34.0 bar (300 and 500 psi) and the percentage of pressure decay after 15 minutes was recorded. At 20.4 bar (300 psi) 5.1% pressure and at 34.0 bar (500 psi) a pressure decay of 7.1% was observed.

Summary of Results. These three results offer compelling evidence that the MICP sealing field demonstration at Gorgas resulted in highly 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 mechanical integrity test of “less than 10% pressure fall off in 15 minutes”.

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 from July through 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. Adie led the effort to mobilize and conduct the MICP wellbore sealing field test at the Gorgas facility in April 2016. 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.

Eric Troyer, a Chemical and Biological Engineering graduate from MSU (December 2015), has worked on the team for the last three years during his undergraduate education. His undergraduate research efforts included screening tirelessly sources of chemicals that can promote precipitation economically (he determined urea fertilizer and calcium 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 will be attending graduate school at the University of California-Berkley in the fall and was recently awarded a fellowship with the National Science Foundation Graduate Research Fellowship Program (NSF GRFP).

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 for further dissemination.

Planned activities during the next reporting period

The major activity planned for next reporting period is to continue to analyze data form the April 2016 MICP wellbore sealing test at the Gorgas facility. Additionally, we are planning to drill several more side wall cores and run another USIT scan over the MICP impacted interval at the Gorgas well.

Products
Conference Presentations

Gerlach, R., Phillips, A., Cunningham, A., Spangler, L. “Biofilm-Mediated Mineral Precipitation Technology – From the Microscale to the Field-Scale” Goldschmidt, Yokohama, Japan June 26-July 1, 2016.

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, helped 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 participated in the April 2016 field test.

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 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 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 2016.

IMPACT

The results of the April 2016 Gorgas MICP sealing test were positively received by Mr. Jim Kirksey and Mr. Wayne Rowe of Schlumberger. Written comments from Jim and Wayne were obtained for the purpose of documenting MICP sealing success from the oil and gas industry perspective. Their comments are below.

Industrial perspective by Jim Kirksey. *“Channels in primary cementing operations occur when drilling mud is not swept from the well during primary cementing placement and remains stranded between the casing and the open hole or another string of casing. The primary contributors to incomplete displacement of drilling mud are lack of proper centralization and incompatible rheological properties of the mud and displacing fluid. Channels are somewhat common and it is generally accepted in industry that it is impossible to repair a channel with traditional squeeze cementing methods. While some channels are benign and pose no threat to overall well integrity; others may contribute to unwanted migration of* *gas and other well fluids. In the recent test at the Gorgas #1 well in Walker County, Alabama a channel left during the primary cementing operation was affected by "bio-cement". A sidewall core was drilled through the casing into the lower area of the channel. Low rate injection (0.75 GPM) was established into the channel and through the defective cement just above the channel. During the bio-mineralization experiment microbes were placed that produced volumes of calcium carbonate to greatly reduce the size of the channel as well as fill in the area of defective cement just above the channel. Success was measured by the loss of ability to inject fluid into the channel, pressure tests, and confirmed by the IBC log which confirmed the new solid material in and above the channel. This is significant as it is one of the first successful attempts to affect a channel in a cemented well"*

Jim Kirksey
Loudon Technical Services

Industrial Perspective by Wayne Rowe. *"One of the most crucial engineering necessities in oil and gas production and the geologic sequestration of carbon is wellbore integrity. Wellbore integrity is assuring wells used for the production or injection of hydrocarbons,* CO_2 *and other fluids maintains the protection and isolation of ground water aquifers and the safe containment of injected fluids. If a well is determined to have leaks or inadequate annulus cement, some form of remediation is required to bring the well into compliance. Traditionally, the most common form of remediation is pumping a cement slurry down a wellbore to the problem area or squeeze target. The area is isolated, and pressure is applied from the surface to effectively force the slurry into voids. In many instances, the amount of pressure required to pump the viscous slurry is excessive and consequently, the treatment is ineffective. The bio-remediation technique is promising because the much lower viscosity of the bio-remediation fluid allows penetration into any leak or void. This ability significantly broadens the range of intervention techniques available to restore wellbore integrity. In the recent field test of the system at the Gorgas site near Parrish, Al – the technique was effective in filling a cement "channel" in the annulus between casing and the formation. The cement channel was identified by an ultrasonic scanning wireline devise used to evaluate the quality of the primary cement. A cement channel is a vertical void that will potentially allow fluid movement between a deep permeable formation into shallower zones. A hole was drilled through the casing opposite the channel and fluid injected at a low rate into the void. The bio-remediation technique was applied in successive descents into the wellbore while the pressure required to inject the mixture was recorded. The injection pressure steadily increased with each application until no more fluid could be injected. After the conclusion of the bio-remediation operation the ultrasonic scanning devise was re-run and the result indicated a significate reduction in the void. The test was concluded by performing a type of Mechanical Integrity Test (MIT) required by most state natural resource regulators. The results of the post remediation MIT meet generally accepted regulatory criteria. It is my opinion that this test was successful and merits testing to further validate this bio-remediation technology as a promising technique to broaden our ability to restore wellbore integrity".*

Wayne Rowe
Carbon Services Operations Manager
Schlumberger Technology Corporation

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 have been revised due to the budget period 1 no cost extension,

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:	10/1/2013	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		558,080
									-
Non-Federal Share			53,559	51,624	-	12,527	16,622		134,331
									-
Total Incurred Costs	6,268	19,082	83,796	104,652	83,125	178,413	217,076	-	692,412
									-
Cumulative Incurred Costs	6,268	25,350	109,146	213,798	296,923	475,336	692,412		692,412
Variance									
Federal Share	157,307	144,493	133,338	110,546	(83,125)	(165,886)	(200,454)	-	96,220
									-
Non-Federal Share	31,739	31,739	(21,820)	(19,885)	-	(12,527)	(16,622)	-	(7,375)
									-
Total Variance	189,046	176,232	111,518	90,662	(83,125)	(178,413)	(217,076)	-	88,844
Cumulative Variance	189,046	365,278	476,796	567,458	(296,923)	(475,336)	(692,412)	-	88,844

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