Oil & Natural Gas Technology

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Quarterly Research Performance

Progress Report (Period Ending 06/30/2017)

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

Project Period (10/1/2014 to 09/30/2018)

Submitted by:
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Signature

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U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

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 was 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 is designed to 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 in an injection well used for water flooding to improve oil recovery in Indiana known as the Rexing #4 well.

After each field demonstration, the following (or equivalent) methods are to be employed to assess effectiveness of the MICP seal: pressure falloff testing, sustained natural gas flow rate testing at the well head, 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 ultrasonic imaging tool (USIT) data in the targeted biomineralization regions, and demonstration of MICP byproducts ($CaCO_3$) in the treated regions on side wall cores. In the case of the new well chosen for the second field demonstration, the return to productivity would be an additional measure of success.

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 sealing in annular spaces representative of field conditions.	3/31/2015	NA	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	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, 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). The subjects of these calls have been: analysis of the first field test results, development of the mobile operations center, and planning of the second field test. A milestone report was submitted April 3, 2017, for completed milestone #5 which reported that

our first field test data has been analyzed and a manuscript is in preparation. A new well has been identified for the second field test currently being planned.

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 downhole 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; (2) a comparison of USIT logs taken before and after MICP treatment of the target interval indicated a significant increase in the solids content after sealing; and (3) pressure fall-off tests after MICP treatment met a definition of mechanical integrity for shut in wells. 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.

Cement Channel Laboratory Experiment

Because the gap size at the new well in Indiana is not completely known but may take significant fluids (i.e. be a large gap), an experiment was run in the laboratory in the cement steel interface reactor. This experiment was performed to determine whether sealing could occur in a larger gap or void. Thus, a 2 mm (0.079 inches) wide gap between a cement and a steel coupon was engineered and constructed (Figure 1). Class H wellbore cement was mixed with water in a 4:10 water to cement ratio by weight and blended in a Hamilton Beach Model 918 blender on high for approximately 30 seconds to allow for sufficient mixing of the cement and water in the slurry. This slurry was then poured into each reactor. After curing, the system was flushed with clean water prior to inoculation with *S. pasteurii* and a pulsed injection of microbes and biomineralization solutions followed. The test protocol was intended to mimic the injection strategy that would be used at the Rexing #4 well. The fixture was re-inoculated each evening prior to sitting overnight.

Figure 1. The cement and steel interface reactor. When the two halves are put together, the interface between the cement and steel is a 2mm (0.079 inches) wide open void.

After 45 calcium pulses over nine days, the apparent permeability was reduced by more than five orders of magnitude from about 3,800 Darcys for the open channel to 0.021 Darcys.

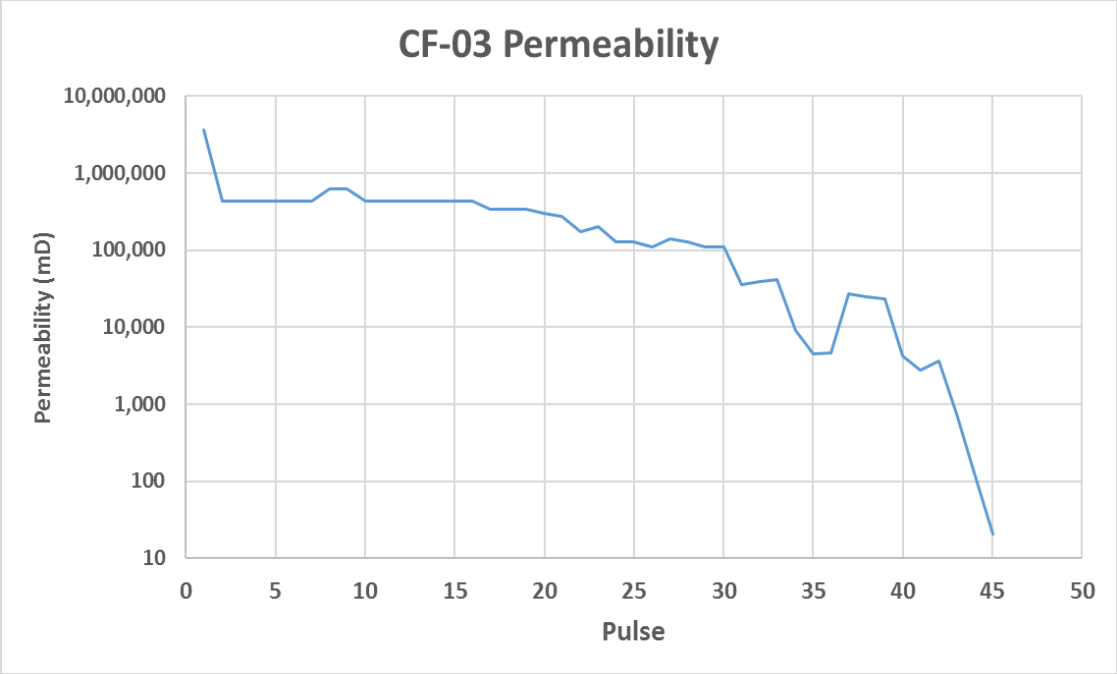

Figure 2. The apparent permeability was reduced more than five orders of magnitude after 45 calcium pulses.

A significant amount of calcite formed in the lower half of the gap (Figure 3). It adhered to both the cement and the steel, with more calcite adhering to the cement.

Figure 3. Significant calcium precipitation (arrow) was observed to have formed in the gap between the cement and steel.

The calcium content of the effluent was measured and subtracted from the influent concentration to estimate the total calcite precipitated. A total of 5.1 g of calcite was deposited (or 1.9 ml using a specific gravity of 2.7). This is equivalent to 24.3% of the original 7.7 ml gap volume. Since most of the precipitation was in the lower half, it could be assumed that about 50% of the lower half was filled. Regardless, sufficient space was filled to effectively plug the gap. This successful demonstration of MICP in a large gap provides evidence that even if the gap size in the Rexing well is large, with enough time on-site the gap could be sealed.

Mobile Mineralization Operations Center Development

MET, MSU, and Jim Kirksey of Loudon Technical Services finalized the layout of the mobile operations center. The final design maintains the major desired functions: (1) operations control and communications; (2) laboratory activities; (3) storage; and (4) pumping (to bailer or downhole). The mobile laboratory is currently under construction.

Planning Second Field Test

The Rexing #4 well lies in southern Indiana. This well is an injection well that was used to perform water flooding to increase oil recovery. A channel formed in the cement resulting in the water traveling through the channel into a thief zone above the targeted oil formation. The advantage of using this well for the second demonstration is that there is oil present in the environment which makes this sealing experiment more applicable in a real-world oil field technology. The final field methods will be determined based on the laboratory experiments performed in the coming months. Paper work was filed in June to change the environmental

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Other organizations involved as partners

Schlumberger (SLB). SLB is providing matching support for this project. During this reporting period, Jim Kirksey and others from SLB participated in the decision to request a change in wells for the second field demonstration.

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) which was used for the first MICP field test.

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 and will be used to model the injection strategy that will be used at Rexing.

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)

Dr. Al Cunningham and Dr. Adrienne Phillips traveled to Rotterdam, Netherlands for the 9th Annual InterPore Conference. A total of $ $2,686.04 was spent for this trip/meeting.

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.

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