Field Test and Evaluation of Engineered Biomineralization Technology for Sealing Existing wells

Project Number: FE0009599

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National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Infrastructure for CCS
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Presentation Outline

Note: This presentation combines results from two closely related DOE projects:


Project DE-FE0004478, Advanced CO₂ Leakage Mitigation using Engineered Biomineralized Sealing Technologies (October 1, 2011- March 31 2015)

• Project Concept
• Benefit to the Program
• Goal and Objectives
• Technical Status
• Accomplishments to Date
• Summary
• Future work
Project Concept

- Sealing unwanted flow paths, underground gas storage
- **Microbially induced calcite precipitation (MICP)**
- Results from lab scale, field scale, and simulation modeling will be reported
Calcite Biomineralization (MICP) Using Ureolytic Bacteria

- $\text{NH}_2\text{CONH}_2 + \text{H}^+ + \text{H}_2\text{O} \leftrightarrow 2\text{NH}_4 + \text{HCO}_3^- \quad (1)$

- $\text{Ca}^{+2} + 2\text{HCO}_3^- \leftrightarrow \text{CaCO}_3(s) + \text{CO}_2 + \text{H}_2\text{O} \quad (2)$

- The enzyme urease present in some bacteria (i.e. (Sporosarcina pasteurii)) hydrolyzes urea to form ammonium which increases pH

- $\text{HCO}_3^-$ is subsequently produced which in the presence of $\text{Ca}^{+2}$ precipitates calcium carbonate (Calcite)
Inlet CaC0₃ Crystals (20hr)

- Add Inoculum *Sporosarcina Pasteurii*
- Add biofilm growth nutrients
- Add Urea and Calcium
- Calcium Carbonate (Calcite) precipitation
**Project Concept**

-MICP sealing with low-viscosity fluids-

- **Cement** is a good technology for large aperture leaks, but is too viscous to plug **small aperture leaks** (small fractures or interfacial delaminations).
- In some cases it is also desirable to plug the **rock formation** near the well.
- A missing tool is a plugging technology that can be delivered via **low-viscosity fluids**

After Nordbotten and Celia, Geological Storage of CO₂, 2012
Benefit to the Program

Program goals being addressed:

Develop and validate technologies to ensure 99 percent storage performance.

Project benefits statement:

The Engineered Biomineralized Sealing Technologies (MICP) projects support Storage Program goals by developing a leakage mitigation technology for small aperture leaks that can be delivered via low viscosity solutions. The technology, if successfully applied, could provide an alternative technology to cement for plugging preferential CO₂ leakage pathways in the vicinity of wellbores.
GOAL: Demonstrate the biomineralization technology for sealing preferential flow pathways in the vicinity of injection wells, thus addressing the DOE goal of storage permanence. This goal is supported by the following Objectives from Project FE0004478 Advanced CO₂ Leakage Mitigation using Engineered Biomineralized Sealing Technologies:

1) Construct and test mesoscale high pressure rock core test system (HPRTS). (Completed)
2) Develop biomineralization seal experimental protocol. (Completed)
3) Creation of biomineralization seal in different rock types and simulating different field conditions. (Ongoing)
GOAL: Demonstrate the biomineralization technology for sealing preferential flow pathways in the vicinity of injection wells, thus addressing the DOE goal of storage permanence. This goal will be accomplished with the following objectives:

(1) Characterize the Alabama well test site. (Completed)
(2) Design protocol for field injection test. (Completed)
(3) Perform field injection test. (Completed)
(4) Evaluate results of field test. (Ongoing)
Technical Status

• Focus the remaining slides, logically walking through the project. Focus on telling the story of your project and highlighting the key points as described in the Presentation Guidelines

• When providing graphs or a table of results from testing or systems analyses, also indicate the baseline or targets that need to be met in order to achieve the project and program goals.
Scales of Experimentation and Modeling

- nm to cm
- μm to dm
- cm to 100s of m
Large Sandstone Core
Boyles sandstone formation, Alabama

76.2 cm (30 inch) x 38.1 cm (15 inch) sandstone core procurement and packer design for “Radial flow”

Hydraulically fractured at $p = 8$ bar (after 1.75 hours)

DOI: 10.1021/es301294q
Radial Flow High Pressure Vessel

Designed and built by Joe Eldring & Alaskan Copper, Seattle, WA USA

Fracture Sealing at 45 bar


Ensuring 99 percent CO₂ storage goal
MICP Model concept

(modified after Ebigbo et. al., WRR 2012)
MICP Modeling of Sandstone
MICP Field Test

Date: April 1 – 11, 2014
Location: Gorgas Power Plant near Jasper Alabama
Injection Zone: Horizontal hydraulic fracture at 1118 feet bgs
Collaborators: Southern Company & Schlumberger Carbon Services

Well location
Gorgas well and Test site

Total well depth 4915 ft
Test was conducted at 1118 ft, bgs
Characterize and prepare the Alabama Test site

- Injection test

- Formation fractured at approx. 960 psi – horizontal pancake fracture at 1118 ft. bgs

- Injection test at 0.5 gpm for 4.5 hours at just over 500 psi

- Falloff analysis indicates approx. 11 mD formation permeability
Hydraulic fracture sealing: Conceptual model
Field Deployment - Fracture Sealing

- Bailer delivery system
- Injection strategy
- Mobile laboratory - microbe cultivation
- Sampling
30 ft (9.1m) injection bailer
 Protocol for biomineralization testing in the field

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<thead>
<tr>
<th>Inoculation injection Components:</th>
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<td><strong>S. pasteurii</strong></td>
<td>2 to 5 E+7 CFU/ml</td>
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<td>Urea</td>
<td>795 gr</td>
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<tr>
<td>NH4Cl</td>
<td>331 gr</td>
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<td>Nutrient Broth</td>
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<th>Calcium Injection Components:</th>
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<td>1285 gr</td>
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<tr>
<td>Urea</td>
<td>795 gr</td>
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<tr>
<td>NH4Cl</td>
<td>331 gr</td>
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<tr>
<td>Nutrient Broth</td>
<td>99 gr</td>
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</table>

| Bailer capacity                  | 3 to 3.75 gallons |
| Dilution Volume                  | 5 to 10 gallons |

Injection of brine through 2.75 inch tubing – Injection of inoculum and calcium/urea fluids using a dump bailer
**Complete sealing** after 3 days:
24 calcium injections, 6 inoculation injections, 15 kg Ca

Yellow colonies
*S. Pasteurii*
MICP model simulation using Gorgas field protocol made prior to field injection

Volume fraction of calcite (0.125 m³ CaCO₃/m³) at the end of the MICP simulation.

25 Ca injections, 11kg of Ca total, 6 Inoculation injections
Accomplishments to Date

The following list summarizes completed project objectives from Project FE0004478 and Project FE0009599

- Construct and test mesoscale high pressure rock core test system (HPRTS) (4478 Objective 1)
- Develop biomineralization seal experimental protocol (4478 Objective 1)
- Characterize the Alabama well test site (9599 Objective 1)
- Design protocol for field injection test (9599 Objective 2)
- Perform field injection test (9599 Objective 3)
Summary

Key Findings

• Mesoscale laboratory experiments, integrated with simulation modeling, were successfully used to develop the protocol for sealing a horizontal hydraulic fracture at the Alabama test well.

• Key microbial process - ureolytic biomineralization- was found to be robust under (non-sterile) down-hole conditions.

Lessons Learned

• Conventional oil field technology can be used to promote MICP in subsurface applications.

Future Plans

• Creation of biomineralization seal in different rock types and simulating different field conditions i.e. sandstone, shale, cement, steel. (4478 Objective 3)

• Evaluate results of field test. (9599 Objective 4)

• Continue development of MICP simulation model.
Acknowledgements

Collaborators
Jim Kirksey and Dwight Peters,
Schlumberger
Richard Esposito, John Poole
Southern Company
Pete Walsh
University of Alabama Birmingham
Anozie Ebigbo, Johannes
Hommel Holger Class, and
Rainer Helmig
University of Stuttgart
Joe Westrich, Bart Lomans,
Andreas Busch,
Shell
Randy Hiebert, Ellen Lauchnor, Lee
Spangler, Joe Eldring, Andy
Mitchell, James Connolly, Peg
Dirckx, CBE/MSU
Appendix

– These slides will not be discussed during the presentation, but are mandatory
Organization Chart
Project DE-FE0004478

Energy Research Institute
Director Lee Spangler

PI: Al Cunningham

Co Investigator: Richard Esposito
Southern Company

Rock Sample Acquisition

Co Investigator: Peter Walsh
University of Alabama at Birmingham

Core Testing

Collaborators: Andreas Busch, Claus Otto
Shell International Exploration & Production B.V.

Ensure field relevance of protocols

Communications

Reporting

Fiscal Administration
# Gantt Chart Project DE-FE0004478

<table>
<thead>
<tr>
<th>Task / Milestone</th>
<th>Description</th>
<th>Q1</th>
<th>Q2</th>
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<td>Project Management &amp; Planning</td>
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<td>Construction of high pressure rock testing systems (HPRTS)</td>
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<td>ScCO2 challenges of mineralized rock</td>
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* Shaded numbered circles are completed milestones


