Wellbore Seal Repair Using Nanocomposite Materials

Project Number DE-FE0009562

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Presentation Outline

• Introduction and overview
• Materials synthesis
• Materials testing and characterization
• Seal system testing
• Numerical simulation
• Summary
Benefit to the Program

- **BENEFITS STATEMENT:** The project involves the development and testing of polymer-cement nanocomposites for repairing flaws in annular wellbore seals. These materials will have superior characteristics compared to conventional materials, ensuring hydraulic isolation of the wellbore after closure. The technology contributes to the Program’s effort of ensuring 99% CO₂ storage permanence.
Project Overview: Goals and Objectives

• (1) Develop and test **nanocomposite seal repair materials** suitable for expected wellbore environments that have **high bond strength** to casing and cement, **high fracture toughness**, and **low permeability**.
  
  – These materials will have superior properties compared to conventional materials to permit improved wellbore seal repair, contributing to the program’s goal of 99% storage permanence.
  
  – Success criteria: Materials shall have superior properties and characteristics compared to conventional materials.
(2) Evaluate the effectiveness of developed materials to repair flaws in *large lab-scale annular seal systems* under conditions expected in wellbores.

- Evaluation and understanding of the expected performance of these materials to repair flaws within sealed wellbores will lead to more confidence in the ability to ensure 99% CO₂ storage permanence.
- Success criteria: The degree to which system permeability to CO₂ is reduced after repair, cost, material availability and ease of use compared to conventional materials.
Nanocomposites - addition of small amounts of nano-scale materials can dramatically alter properties of materials such as polymers, composites, and cements.

- Strength
- Ductility
- Reduce shrinkage
- Thermal stability
- Resistance to degradation
Materials

Base materials
- Siloxane
- Novolac

Nanoparticles
- MWCNTs
- Nanoclay
- Nanoalumina
- Nanosilica

Nanocomposites
Flowability of PCNC
Bond strength characterization

- Slant shear test – a direct measure of nanocomposite – steel bond strength
Bond Strength of PCNC and Steel
PCNC – Steel slant shear behavior
Examining the effect of high temperature and pressure

Temp: 80 °C, Pressure 10 MPa
No effect of elevated temperature and pressure on performance of PCNC

![Bar graph showing bond strength comparison between PCNC11, PCNC14, and PCNC17 cured at ambient conditions and elevated temperature and pressure.](image_url)
Flow through damaged and repaired wellbore systems
Pressure vessel

Independent control of confining pressure to 30 MPa and casing pressure to 20 MPa.
Gas Permeameter

Gas pressures to 14 MPa.
Permeability range $>10^{-12}$ to $<10^{-21}$ m$^2$
Specimen preparation

- Microannulus
  - Large
  - Small
- Cement fracture
Flow dominated by flaws

Cubic law for hydraulic aperture

\[ h^3 = \frac{12kA}{W} \]
Repair of damaged wellbores

1. No pressure

2. Separate pressurized system

3. In pressure vessel
Microannulus repair using nanocomposite

Confining pressure = 200 psig
Internal pressure = 200 psig
Pore pressure = 100 psig

Flow rate (SLM)

Before repair

After repair
Cement fracture repair using nanocomposite

Before repair

Internal pressure = confining pressure
Gas pressure = 50 psig
Repair response to stress cycles

After two stress cycles

- Microfine repair
- Nanocomposite repair

Pmeability (m^2)
Repaired with microfine cement
Repaired with nanocomposite
Penetrability

Microfine penetrated 75 μm gap

Nanocomposite penetrated 13 μm gap
Response of microannulus and repaired microannulus to thermal stress

- Circulate cold and hot water through casing to induce casing expansion and contraction
Microannulus model

Material model for the microannulus that describes permeability changes in response to changes in confining and/or casing pressure and temperature.
Wellbore model incorporating microannulus

Microannulus space can be modeled as

- Microannulus
- Open
- Cement
- Repair material
Accomplishments to Date

– Synthesized and characterized a number of nanocomposite and reference materials. For some nanocomposites:
  * Acceptable flowability
  * Bond strength and fracture toughness substantially increased
– Testing of wellbore seal systems
  * Developed experimental methods
  * Testing pre- and post-repair condition
– Simulation model developed
Synergy Opportunities

– Wellbore damage
  • Experimental methods and data set on permeability under different stress conditions can be used by/compared to work of others.

– Wellbore repair
  • Developed repair material can be used in field applications.

– Wellbore modeling
  • Model for wellbore behavior that can be applied to large scale applications.
Summary

– Nanocomposites are being developed and tested with favorable properties as seal repair materials.

– Future Plan: Continue material synthesis and testing with accompanying testing and evaluation of seal system repair.
Appendix
Carbon Storage R&D Project Review Meeting
August 18-20, 2015

Organization Chart

Stormont (UNM) PD/PI

Taha (UNM) PI
Materials synthesis and testing

Genedeytal Graduate student

Ahmad Graduate student

Gomez Student intern

Matteo/Dewers (Sandia) Co-investigators
Materials evaluation and numerical simulations

Raymer Student intern
Gantt Chart

1 - Project Management
2 - Synthesis of materials
3 - Macroscale characterization
   3.1 - Bond strength
   3.2 - Fracture toughness
4 - Microscale characterization
   4.1 - NMR studies
   4.2 - XRDA, TGA, SEM studies
   4.3 - Nanoscratch testing
5 - Integrated testing of seal repair
   5.1 - Sample preparation
   5.2 - Seal repair test
   5.3 - Post-test examination
   5.4 - Test modeling

Quarterly reports
Quarterly and annual reports
Updated project management plan
Material selection for integrated tests
Tasks not yet underway
Milestones

Carbon Storage R&D Project Review Meeting
August 18-20, 2015
Publications generated from project


Bibliography

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Acknowledgements

We thank Steve Sobolik and Steven Gomez for their contributions to the modeling work, and Moneeb Genedyetal, Rashid Ahmad and Joshua Ellison for their help with the laboratory work.

This material is based upon work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant Number DEFE0009562.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.