Development of Swelling-Rate-Controllable Particle Gels to Enhance CO$_2$ Flooding Sweep and Storage Efficiency

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Baojun Bai

Missouri University of Science and Technology

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Transforming Technology through Integration and Collaboration
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Presentation Outline

• Benefit to the Program
• Project Overview: Goals and Objectives
• Methodology
• Expected Outcomes
• Task/Subtask Breakdown
• Milestones
• Summary
• Appendix
Benefit to the Program

• Program goals being addressed
  - Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.

• Project benefits statement
  - The research project is to develop novel environmental friendly swelling-rate-controllable particle gels to improve CO$_2$ sweep and storage efficiency. The new materials will overcome some distinct drawbacks inherent in the in-situ gels that are traditionally used for conformance control. The technology, when successfully demonstrated, will provide a novel cost-effective technology to the Carbon Storage Program’s effort of improving reservoir storage efficiency while ensuring containment effectiveness.
Project Overview: Goals and Objectives (1)

- **Overall Goal:** to develop a novel particle-based gel technology that can be used to enhance CO$_2$ sweep efficiency and thus improve CO$_2$ storage in mature oilfields.

- **Project Objectives:**
  - To synthesize a series of environmental-friendly and swelling-rate-controllable particle gels for CO$_2$ conformance control.
  - To understand the transport behavior and mechanisms of the particle gels in different high permeable features.
  - To understand the plugging mechanisms of particle gels for different types of reservoir problems.
Project Overview: Goals and Objectives (2)

• Relevance to Program Goals
  – Novel materials will improve CO$_2$ storage efficiency while ensuring containment effectiveness.

• Success criteria
  – Swelling Rate of particle gels
  – Thermo-stability of particle gels in CO$_2$
  – Plugging Efficiency of particle gels
  – Successful delivery of particle gels into target locations
  – New mechanistic models to characterize particle propagation.
Methodology

We will manage and carry out the project to develop and test novel particle gels with particle sizes ranging from nano- to milli-meter diameters, including

- Bench-scale synthesis and characterization of the particles.
- Analyze experimentally the performance of these gels by conducting core flooding tests.
- Develop a mathematical model which will characterize particle gel behavior in various porous media.

The project involves research efforts in the area of material synthesis and a series evaluation work in lab, including the rheology properties of particle gels and their thermo-stability at a supercritical fluid under reservoir conditions, core flooding tests using different porous media models.
Conformance Problem Classifications

- **Wellbore Problems**
  - Flow behind casing
  - Casing leaks

- **Near Wellbore Problems**
  - High-permeability matrix-rock strata without crossflow

- **Far-wellbore Reservoir Problems**
  
  (a) Overriding and reservoir strata with crossflow
  (b) High permeability streaks
  (c) Fracture channeling
  (d) Solution channels
Gels Used for Conformance Control

- In-situ gel systems: Gelant is injected into formation and gel is formed under reservoir conditions after placement. Gelation occurs in the reservoir.

- Preformed gel systems: Gel is formed in surface facilities before injection, and then gel is injected into reservoirs. No gelation occurs in a reservoir.
Preformed Particle Gel (PPG)

(a) Before swelling  (b) After swelling

Cross-linked polyacrylamide powder, Super Absorbent Polymer

Size ranging from nano-meter to millimeter
Advantages Preformed Particle Gels over In-Situ Gels

• Inherent disadvantages of In-Situ Gel

  Crosslinking reactions and gel quality are strongly affected by
  – Shear of pump, wellbore and porous media
  – Adsorption and chromatography of chemical compositions
  – Dilution of formation water

• Particle thermo-stability is not very sensitive to formation water salinity

• Single component and easy operation in oilfields
Expected Outcomes

• Develop a novel particle-based gel technology that can be used to enhance CO₂ sweep efficiency and improve CO₂ storage efficiency in mature oilfields, including
  – Synthesize novel environmental-friendly and swelling-rate-controllable preformed particle gels with particle sizes ranging from nanometer to millimeter level.
  – Understand the transport behavior and plugging mechanisms of the particle gels in different type of high permeable features.
  – Develop methods to deliver and place the particle gels in target areas.
  – Develop mathematical models to predict the transport of particles through porous media.
  – Provide the criteria of well candidate selection.
Task/Subtask Breakdown (1)

• Task 1.0. Project management, planning, and reporting.

• Task 2. Synthesis and characterization of particle gels
  – Subtask 2.1 Micro- to millimeter sized particle gels synthesis and evaluation
  – Subtask 2.2 Nanoparticle gels synthesis and evaluation
Millimeter-sized Particle Synthesis

- Monomer
- Initiator
- Cross-linker
- Additives

Polymerization

3-D Bulk PG gel

Dry, Grind, and Screen

PPG
Nano-gel Synthesis

Start

Composition from mm-size Particle

ADJUSTMENT

Synthesis in Super Critical CO₂ Condition

EVALUATE

Proper Size and Distribution?

YES

Proper Swelling Rate and Strength?

YES

Thermo-stable in CO₂?

YES

Coreflooding

NO

NO

NO
Task/Subtask Breakdown (2)

- Task 3. Transport behavior of particle gels through different types of porous media and their plugging efficiency to supercritical CO\textsubscript{2} fluid.
  - Subtask 3.1 Develop criteria for particles passing through pore throats and open fractures
  - Subtask 3.2 Conduct core-flooding tests to understand the effect of particle gels on CO\textsubscript{2}/water/oil flow
  - Subtask 3.3 Delivery of nano-gels for In-depth placement
  - Subtask 3.4 Development of mechanistic mathematical models based on experimental results
Models for Core Flooding Tests

Screen models for
- Passing ratio
- Gel strength
- Threshold pressure

Conduits models
- Open channels
- Closed Channels
Models for Core Flooding Tests

Sandpack models
(Loose sand, hydraulic fractures)

Core Flooding with Multiple Pressure taps
(Consolidated formation)
<table>
<thead>
<tr>
<th>Technical Tasks</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
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<tbody>
<tr>
<td>1.0 Project management and planning and reporting</td>
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<tr>
<td>2.0 Synthesis and characterization of particle gels</td>
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<tr>
<td>2.1 Synthesis and characterization of micro- to millimeter-sized particle gels</td>
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<td>2.2 Synthesis and characterization of CO₂-based polymer network nano-particle gels at supercritical CO₂ fluids</td>
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<td>3.0 transport behavior of millimeter-sized particle gel through fractures or fracture-like channels and their plugging efficiency to supercritical CO₂ fluids</td>
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<tr>
<td>3.1 develop criteria for particles passing through pore throats and open fractures</td>
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<tr>
<td>3.2 conduct core-flooding tests to understand the effect of particle gels on CO₂/water/oil flow</td>
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<td>3.3 deliver nano-particle gels for in-depth placement</td>
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<td>3.4 develop the mathematical models</td>
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<tr>
<td>Project Report</td>
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## Milestones

<table>
<thead>
<tr>
<th>Task/Subtask</th>
<th>Milestone Title</th>
<th>Planned Completion Date</th>
<th>Verification method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Project Management Plan</td>
<td></td>
<td>PMP file</td>
</tr>
<tr>
<td>1.0</td>
<td>Kickoff Meeting</td>
<td>08/18/15</td>
<td>Presentation file</td>
</tr>
<tr>
<td>2.1</td>
<td>Synthesize large size (10 µm-mm) swelling delayed particle and compete characterizations</td>
<td>09/30/16</td>
<td>Summary report or presentation file</td>
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<tr>
<td>2.2</td>
<td>Synthesize nano- and micro-sized swelling delayed particle and compete characterizations</td>
<td>09/30/17</td>
<td>Summary report or presentation file</td>
</tr>
<tr>
<td>3.1</td>
<td>Develop criteria for particle passing through pore throats and fractures</td>
<td>09/30/16</td>
<td>Presentation file</td>
</tr>
<tr>
<td>3.2</td>
<td>Understand the effect of particle gel on water/oil/CO₂ flow</td>
<td>09/30/17</td>
<td>Summary report or presentation file</td>
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<tr>
<td>3.3</td>
<td>Understand nano-particle transport mechanisms through porous media</td>
<td>09/30/18</td>
<td>Summary report presentation file</td>
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<tr>
<td>3.4</td>
<td>Develop mathematical models to characterize particle flow behavior</td>
<td>09/30/18</td>
<td>Summary report or presentation file</td>
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<td>Papers</td>
<td>Publish at least 3 peer-reviewed papers</td>
<td>09/30/18</td>
<td>Accepted or published papers</td>
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<td>Presentations</td>
<td>Make at least 4 presentations in conferences</td>
<td>09/30/18</td>
<td>Presentation files</td>
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<td>Final Report</td>
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<td>09/30/18</td>
<td>Report</td>
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Summary

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Acknowledgement

• Department of Energy
• Sponsor office of Missouri University of Science and Technology
Appendix

– Deliverables
– Decision points
– Organization Chart
– Risk Analysis
– Synergy Opportunities
Deliverables

- Project Management Plan.
- Project Fact Sheet
- Data Submitted to NETL-EDX. Will include: 1) various datasets and files as appropriate, 2) metadata, 3) software/tools, and 4) articles developed as part of this project.
- The periodic, topical, and final reports
- Website to house all of the quarterly updates, annual reports, and presentations for interested parties.
# Decision Points

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<th>Phases</th>
<th>Success Criteria</th>
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| Phase 1         | 1. The synthesized particle gels should be thermo-stable in supercritical CO₂ for more than 6 months.  
                           2. The swelling rate of synthesized particle gels can be controlled from a few hours to up to a few months.  
                           3. The nano-particle gels can transport through common porous media.  
                           4. The new particle gels can reduce CO₂ permeability in fractures, fracture-like channels and high permeability rocks and their plugging efficiency should be high than 90%. |
| (06/15/15 – 09/30/17) |                                                                                |
| Phase 2         | 1. The transport mechanisms of nanoparticle through porous media can be understood.  
                           2. New mechanistic models will be obtained through lab data analysis. |
| (10/01/17 – 09/30/18) |                                                                                |
Organization Chart

PI: Baojun Bai
Co-PI: Mingzhen Wei

Senior investigator: Dr Lizhu Wu
Technician: Ninu Maria
Graduate Students
  Mr. Jingyang Pu
  Ms. Xindi Sun
  Mr. Yifu Long
Risk Analysis

• Technical risks-Low risk
  – Particle gel thermo-stability under CO2 conditions
  – Delivery of nano-particle into the in-depth of a reservoir

• Environmental, health, or safety issues:
  – Control residual monomer amount in final products

• Resources and management issues
  – University support structure and PI experience in project management
Synergy Opportunities

– A better reservoir characterization will help to identify conformance problems, which is necessary to optimize a gel treatment design.

– Understanding reservoirs helps design a better particle gel for conformance control