Development of Swelling-Rate-Controllable Particle Gels to Enhance CO_2 Flooding Sweep and Storage Efficiency

Project No. DE-FE0024558

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U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Transforming Technology through Integration and Collaboration

August 18-20, 2015

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

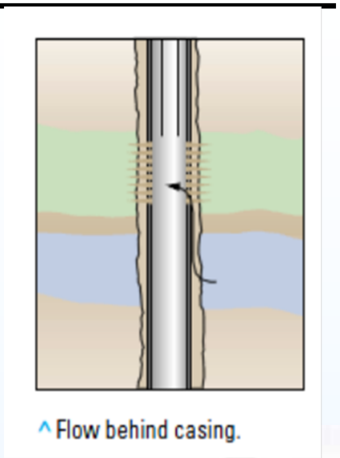
We will manage and carry out the project to develop and test novel particle gels with particle sizes ranging from nano- to milli-meter diameters, including

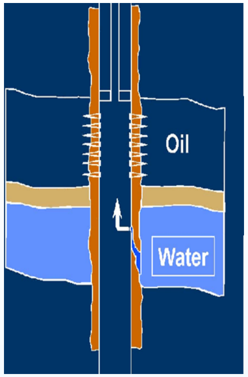
- Bench-scale synthesis and characterization of the particles.
- Analyze experimentally the performance of these gels by conducting core flooding tests.
- Develop a mathematical model which will characterize particle gel behavior in various porous media.

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.

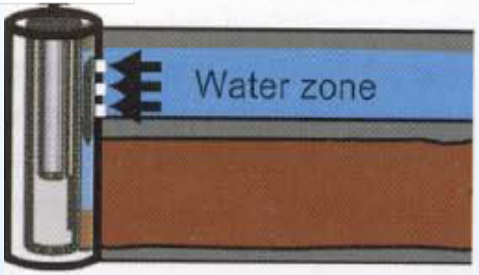
Conformance Problem Classifications

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

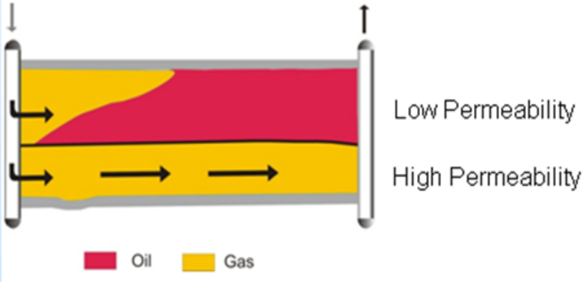




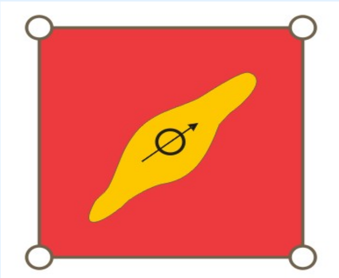
- **Near Wellbore Problems**
  - High-permeability matrix-rock strata without crossflow



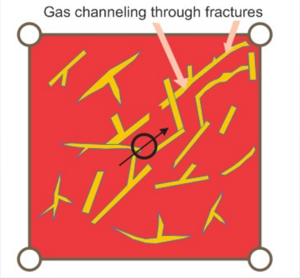
- **Far-wellbore Reservoir Problems**



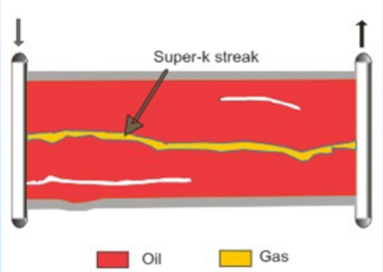
(a) Overriding and reservoir strata with crossflow



(b) High permeability streaks



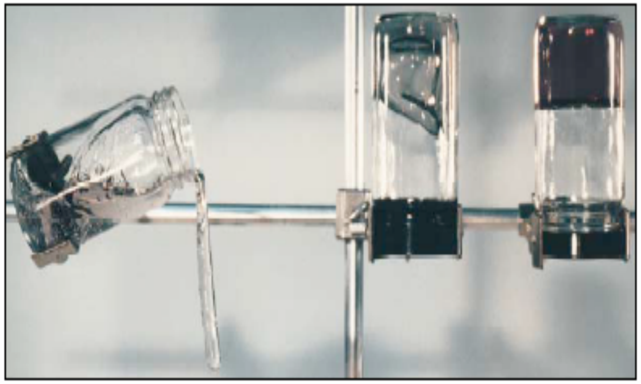
(c) Fracture channeling



(d) Solution channels

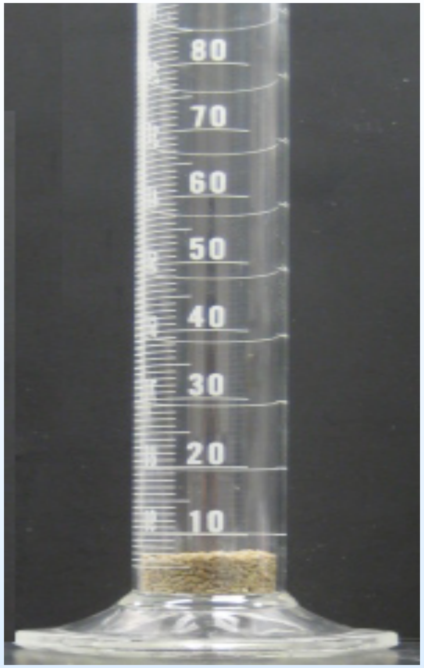
Gels Used for Conformance Control

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

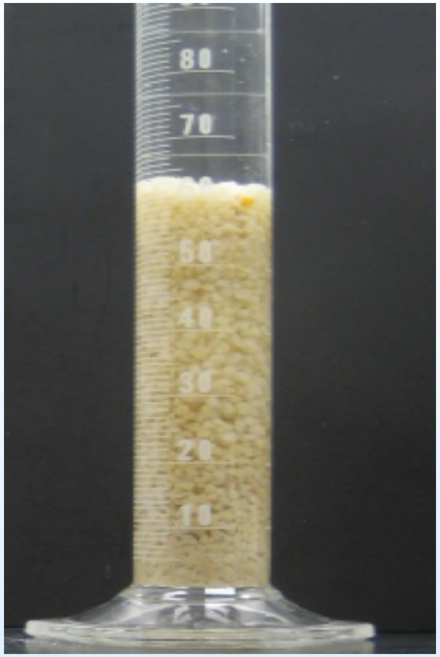


- Preformed gel systems: Gel is formed in surface facilities before injection, and then gel is injected into reservoirs. No gelation occurs in a reservoir.

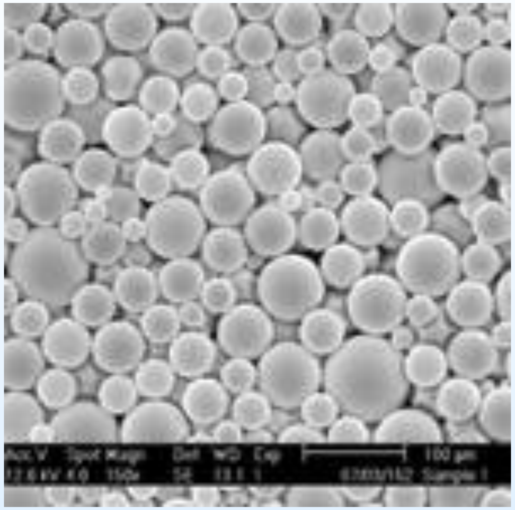
Preformed Particle Gel (PPG)



(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**

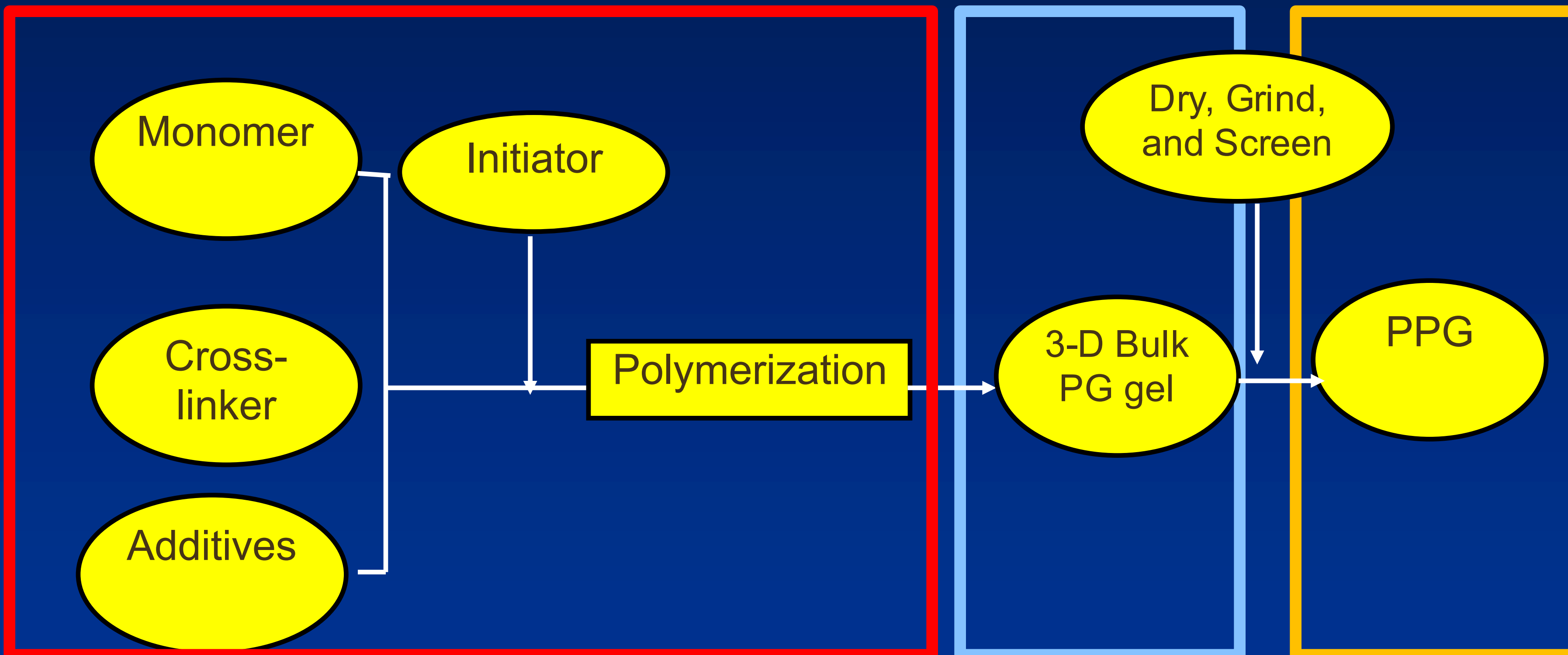
Expected Outcomes

- **Develop a novel particle-based gel technology that can be used to enhance CO_2 sweep efficiency and improve CO_2 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.**

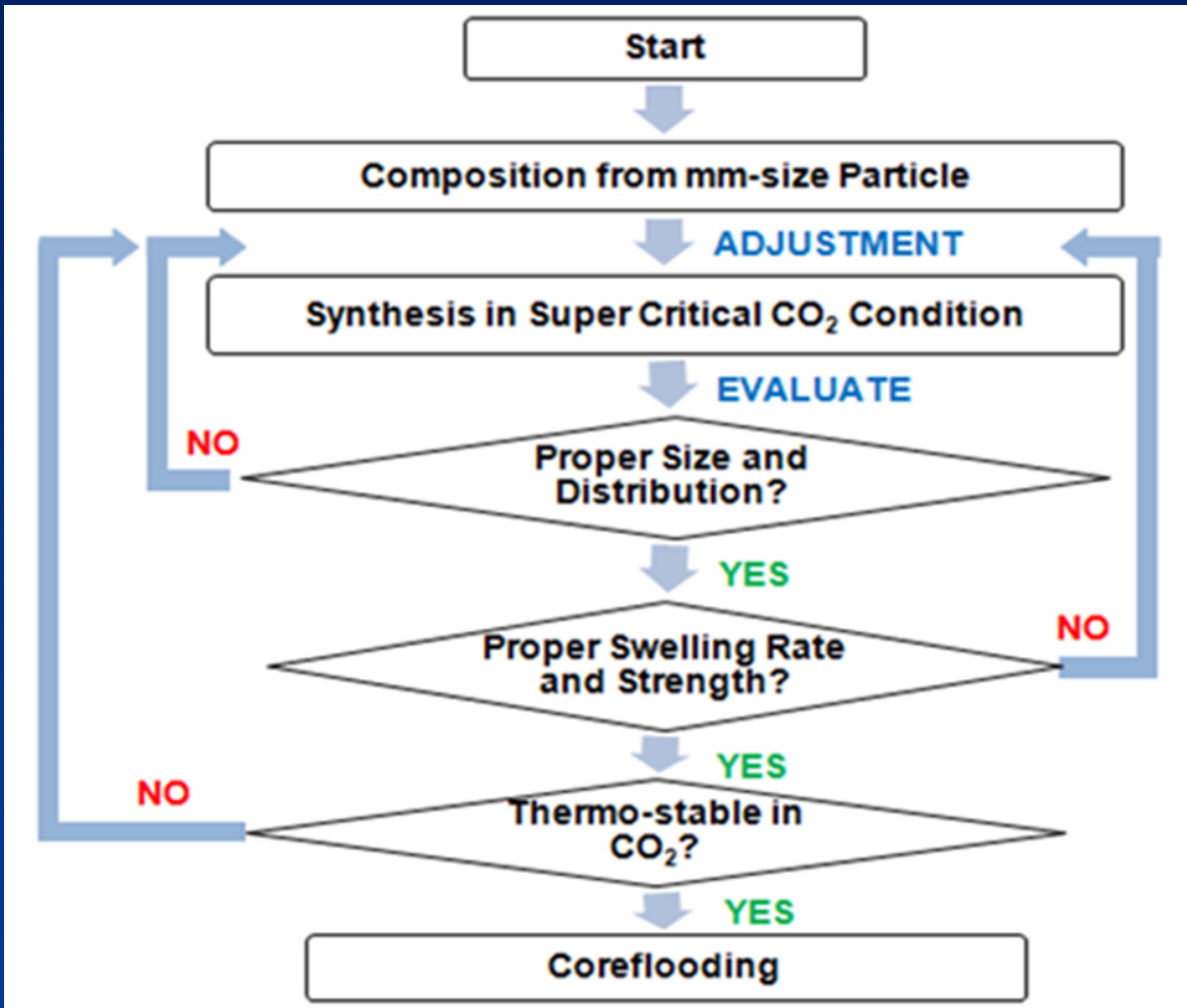
Task/Subtask Breakdown (1)

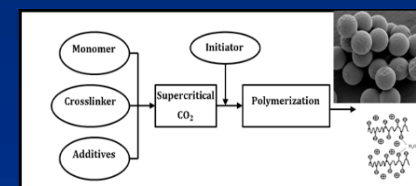
- Task 1.0. Project management, planning, and reporting.
- Task 2. Synthesis and characterization of particle gels
  - Subtask 2.1 Micro- to millimeter sized particle gels synthesis and evaluation
  - Subtask 2.2 Nanoparticle gels synthesis and evaluation

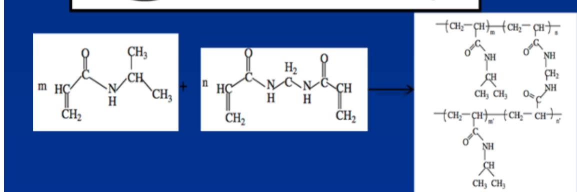
Millimeter-sized Particle Synthesis



Nano-gel Synthesis



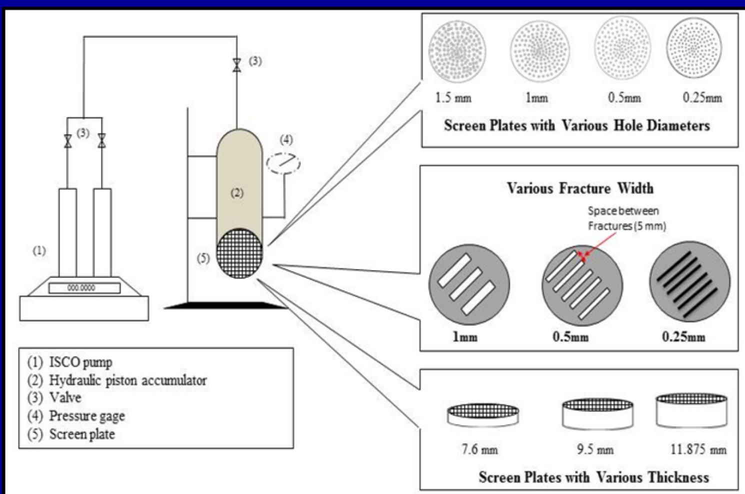




Task/Subtask Breakdown (2)

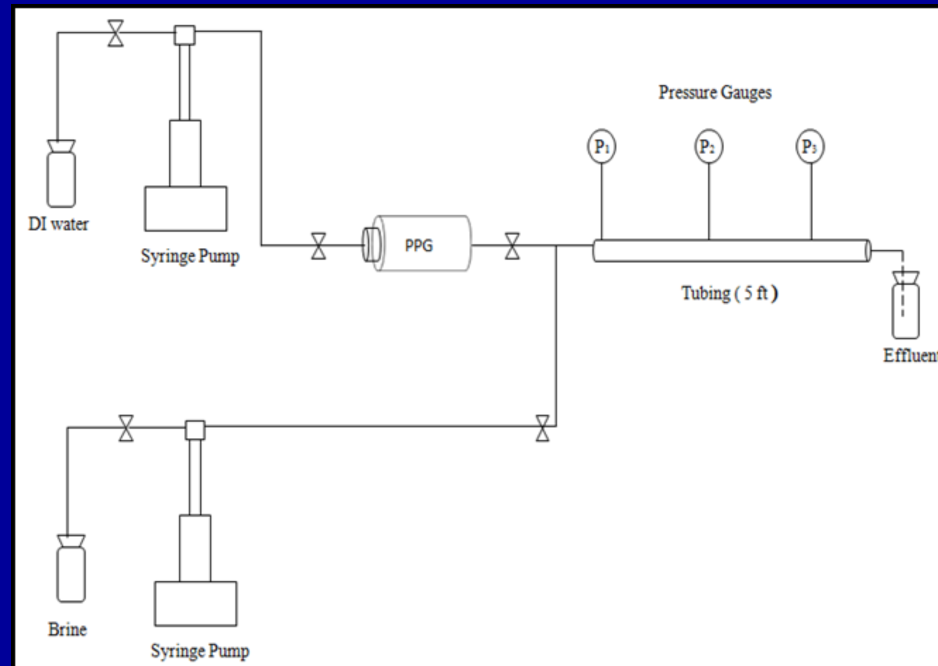
- Task 3. Transport behavior of particle gels through different types of porous media and their plugging efficiency to supercritical CO_2 fluid.
  - Subtask 3.1 Develop criteria for particles passing through pore throats and open fractures
  - Subtask 3.2 Conduct core-flooding tests to understand the effect of particle gels on CO_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

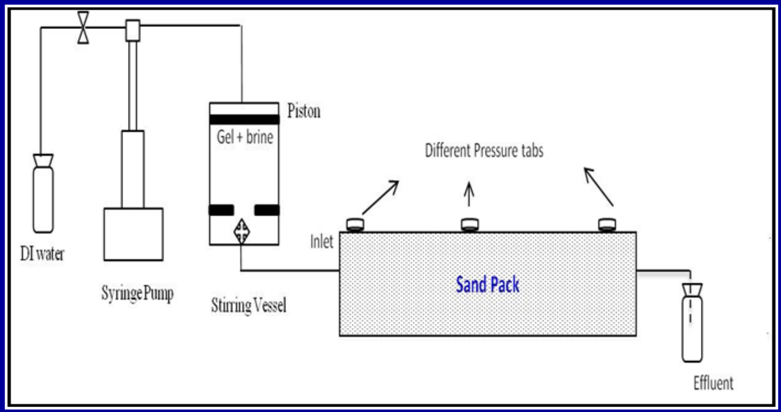
- Passing ratio
- Gel strength
- Threshold pressure

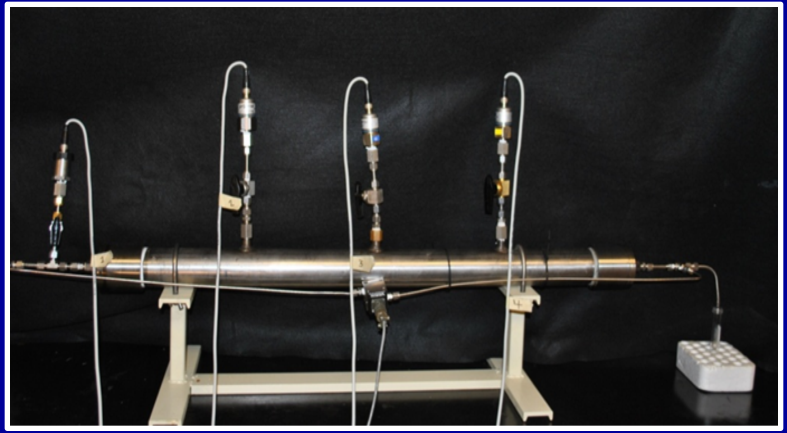


Conduits models

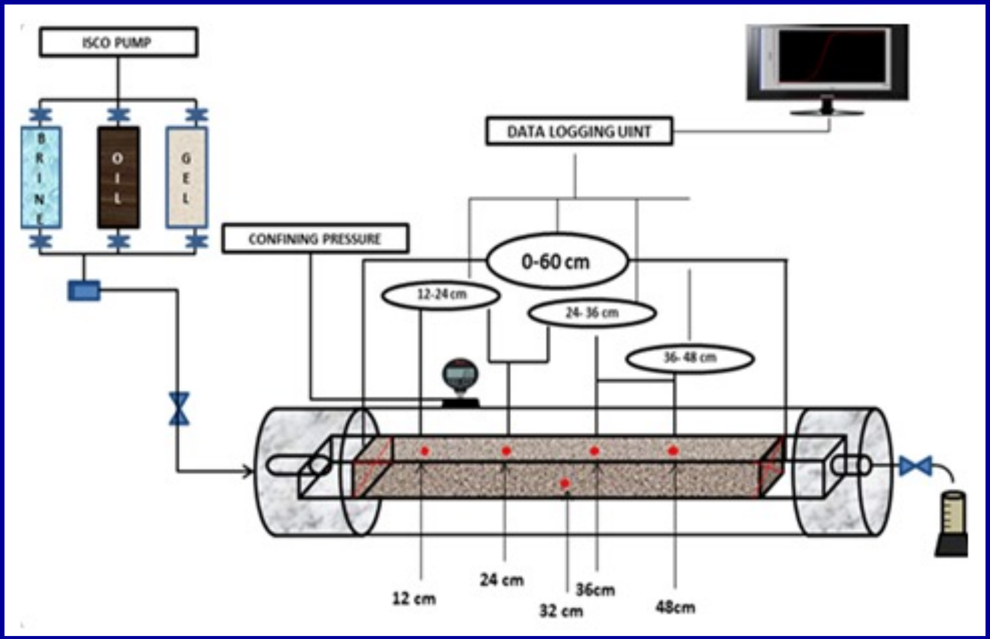
- Open channels
- Closed Channels

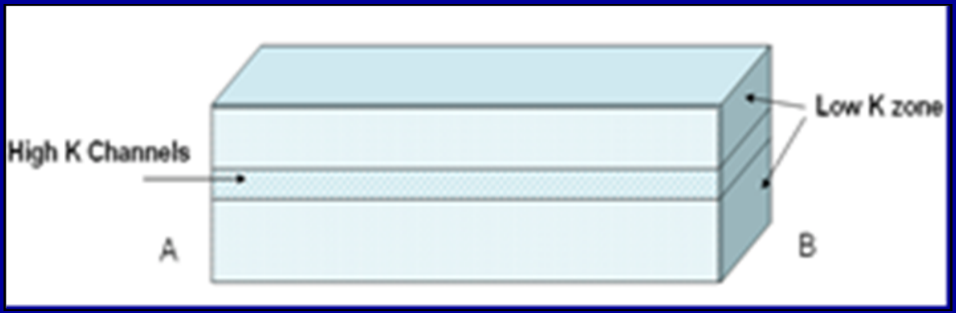
Models for Core Flooding Tests





Sandpack models
(Loose sand, hydraulic fractures)





Core Flooding with Multiple Pressure taps
(Consolidated formation)

Proposed Schedule

Technical Tasks	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1.0 Project management and planning and reporting												
2.0 Synthesis and characterization of particle gels												
2.1 Synthesis and characterization of micro- to millimeter-sized particle gels												
2.2 Synthesis and characterization of CO_2-based polymer network nano-particle gels at supercritical CO_2 fluids												
3.0 transport behavior of millimeter-sized particle gel through fractures or fracture-like channels and their plugging efficiency to supercritical CO_2 fluids												
3.1 develop criteria for particles passing through pore throats and open fractures												
3.2 conduct core-flooding tests to understand the effect of particle gels on CO_2/water/oil flow												
3.3 deliver nano-particle gels for in-depth placement												
3.4 develop the mathematical models												
Project Report	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	QR	FR

Milestones

Task/ Subtask	Milestone Title	Planned Completion Date	Verification method
1.0	Project Management Plan		PMP file
1.0	Kickoff Meeting	08/18/15	Presentation file
2.1	Synthesize large size (10 µm-mm) swelling delayed particle and compete characterizations	09/30/16	Summary report or presentation file
2.2	Synthesize nano- and micro-sized swelling delayed particle and compete characterizations	09/30/17	Summary report or presentation file
3.1	Develop criteria for particle passing through pore throats and fractures	09/30/16	Presentation file
3.2	Understand the effect of particle gel on water/oil/CO_2 flow	09/30/17	Summary report or presentation file
3.3	Understand nano-particle transport mechanisms through porous media	09/30/18	Summary report presentation file
3.4	Develop mathematical models to characterize particle flow behavior	09/30/18	Summary report or presentation file
Papers	Publish at least 3 peer-reviewed papers	09/30/18	Accepted or published papers
Presentations	Make at least 4 presentations in conferences	09/30/18	Presentation files
Final Report		09/30/18	Report

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

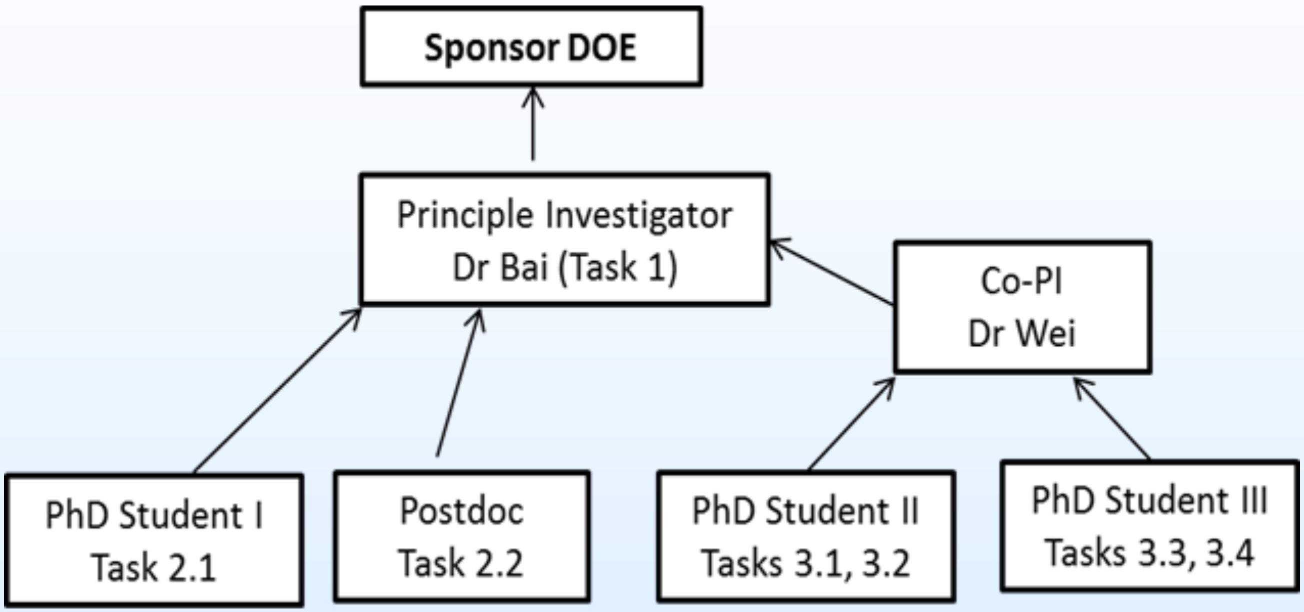
Deliverables

- 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

Phases	Success Criteria
Phase 1 (06/15/15 – 09/30/17)	1. The synthesized particle gels should be thermo-stable in supercritical CO_2 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 CO_2 permeability in fractures, fracture-like channels and high permeability rocks and their plugging efficiency should be high than 90%.
Phase 2 (10/01/17– 09/30/18)	1. The transport mechanisms of nanoparticle through porous media can be understood. 2. New mechanistic models will be obtained through lab data analysis.

Organization Chart



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Technician: Ninu Maria
Graduate Students
- Mr. Jingyang Pu
- Ms. Xindi Sun
- Mr. Yifu Long

PI: Baojun Bai
Co-PI: Mingzhen Wei

Risk Analysis

- Technical risks-Low risk
  - Particle gel thermo-stability under CO_2 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