Controlling Sustainability of Hydraulic Fracture Permeability in Ductile Shales

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Advisors and collaborators

- Dr. Russ Ewy (Recently retired, Chevron Energy Technology Company)
- Prof. Mehdi Mokhtari (Univ. Louisiana/ Tuscaloosa Marine Shale Laboratory)
- Prof. Mileva Radonjic (Oklahoma State Univ./ Caney Shale Laboratory)
- HFTS Project
- Adam Jew (SLAC), Joe Morris (LANL), Dustin Crandall (NETL)
Presentation Outline

➢ Technical Status
  o Motivation & Background
  o Project Outline
    o **Highlights from lab experiment and numerical modeling**

➢ Accomplishment to Date

➢ Lesson Learned

➢ Synergy Opportunities

➢ Project Summary
Technical Status
Motivation and Objectives

Thin, near-leading-edge fractures and tributary cracks in a HF system
• Contribute to a large drainage footprint
• But are vulnerable to premature permeability declines due to proppant crushing (brittle shale) and embedment (ductile shale)
Motivation and Objectives

Big question/Technology goal of this project

- Can we chemically manipulate shale-proppant interaction and hydraulic fracture closure (permeability reduction)?

- If so, how do we achieve this?
Motivation and Objectives

Possible method for proppant crushing reduction

Brittle Shale

Crushed proppant

Controlled acid treatment

Pores from dissolved carbonate

Soft zone (dissolution)

Possible method for proppant embedment reduction

Ductile Shale

Controlled mineral precipitation

Intentionally precipitated carbonates from reservoir fluid

Proppant embedment

Optimum propping?
Project Outline

**Lab experiment**
- High-P/T visualization test system development
- Initial mineral precipitation tests

**Numerical/theoretical modeling**
- Identification of target minerals for precipitation
- Initial THMC modeling (TOUGH-ReactMech)

**Year 1**
- Shale brittleness/proppant crushing reduction tests (Wolfcamp/HFTS shale)
- Shale ductility/proppant embedment reduction tests (TMSL shale)

**Year 2**
- Tests with realistic reservoir & fracking fluid chemistry
- TOUGH-FLAC elasto-plastic, viscoelastic, poroelasto-plastic proppant-embedment modeling
- CRUNCHFLOW reactive transport modeling

**Year 3**
- Proof-of-concept tests on electromigration precipitation enhancement
- Electromigration-enhanced precipitation modeling
Experimental Setup: Test System

- Customized high P-T oedometric compaction cell
- Optical visualization

Actual test max effective stress: 27 MPa (3920 psi)
- test temperature: 120-125°C
- test pore pressure: 10.3 MPa (1500 psi)
Experimental Setup: Test System

- Monolayer/sub-monolayer proppant is pressed against the surface of a shale disc
- Top half of the “fracture” is a transparent, sapphire window

Quartz sand (dia. 1-1.5 mm)

Shale disc (dia. ~44 mm)
Experimental Setup: Test System

- Visualization is facilitated by the UV-fluorescence technique
- Semi-quantitative measurement of fracture aperture and proppant geometry
Result: Brittleness Reduction (Wolfcamp/HFTS shale)

- Examined the impact of acid treatment ("acid spearhead") on clay and carbonate rich shales (Wolfcamp shale, HFTS project)
- Conducted long-term (~2 weeks) in-situ visualization experiments

**Carbonate-rich, heterogeneous Wolfcamp shale**

Effective stress: 27 MPa
Temperature: 123°C
Pressure: 10.3 MPa
Duration: 2 weeks
Acid pretreatment: 15% HCl (room T)
Result: Britteness Reduction (Wolfcamp/HFTS shale)

- Severe proppant crushing was observed for both cases
Result: Brittleness Reduction (Wolfcamp/HFTS shale)

- Acid-induced softening effect was not obvious for this shale
Result: Brittleness Reduction (Wolfcamp/HFTS shale)

• From direct in-situ observations, proppant “survivability” is determined.

\[
\text{Survivability} \equiv \frac{\# \text{ of intact and load-bearing grains}}{\# \text{ of all the grains}}
\]
Result: Ductility Reduction (Tuscaloosa Marine shale)

Solid composition of TMS in-situ brine

Key Ingredients of Lab Brine

- **NaCl**: 9.66 g/100g
- **CaCl$_2$$\cdot$2H$_2$O**: 4.03 g/100g

(More realistic brine used in later study)

Bi-carbonate additive to proppant/fracking fluid

CaCl$_2$+2NaHCO$_3$(aq)→CaCO$_3$↓+2NaCl(aq)+H$_2$O+CO$_2$↑

Carbonate minerals

Cray-rich and ductile (with some water sensitivity)

Water-cut core  Oil (OMS)-cut core
Result: Ductility Reduction (Tuscaloosa Marine shale)

"Uniform" proppant
No additives

"Uniform" proppant
With additives

Test conditions
- Pre-saturation with "realistic" brine (7 days)
- Temperature 120°C
- Max. effective stress 27 MPa (3920 psi)
- Fluid pressure 10.3 MPa (1500 psi)

Proppant + fracking fluid
- pH 9.2
- Guar gum
- K metaborate (crosslinker)
- Ammonium persulfate (delinker)
- Na bicarbonate (powder)
- 1-1.5mm D quartz sand

Clouding due to produced shale fines
Precipitated minerals on the window surface
Result: Ductility Reduction (Tuscaloosa Marine shale)

Clustered proppant with bicarbonate additive, bound by high concentration guar gum

Binder (such as guar gum gel)

Carbonate precipitation

HiWAY (Schlumberger)
Flow-channel fracturing technique

Maximize oil and gas flow through hydraulic fractures by creating infinite-conductivity channels in your proppant pack.
Result: Ductility Reduction (Tuscaloosa Marine shale)

- Precipitation reduced both short and long-term fracture compaction and proppant embedment
- Clustered proppant distribution is more effective
- Repeatedly observed and confirmed linear and bi-linear log(t) behavior
Result: Ductility Reduction (Tuscaloosa Marine shale)

TOUGH-FLAC modeling of proppant embedment

- Time-dependent creep law (empirical)
  \[ \varepsilon_{\text{creep}} = A + B \log(t + t_0) \]
  \[ \dot{\varepsilon}_{\text{creep}} = \frac{B}{t + t_0} \]
- Interference between neighbors seems to lead to a “kink”
Result: Ductility Reduction (Tuscaloosa Marine shale)

[Long-term flow resistance changes]

Without proppant additive

With proppant additive

[Uniform proppant]
Precipitated minerals clog proppant packs

[Uniform proppant]
Proppant embedment+matrix “heaving” reduces permeability

[Clustered proppant]
Permeability preserved in spite of mineral precipitation
Result: Ductility Reduction (Tuscaloosa Marine shale)

Surface Precipitation

[Uniform w/additive]  [Clustered w/additive]

- Clear, abundant carbonate precipitation on the surface
- But little precipitation signatures within the shale matrix
Result: Ductility Reduction (Tuscaloosa Marine shale)

Short-term, elasto-plastic embedment

Surface precipitation is most effective

Long-term, creep embedment

In-matrix precipitation is most effective
Next Step: Ductility Reduction

- Reactive-transport modeling (CRUNCHFLOW) also predicts little precipitation with the shale matrix.

Next (and the final) phase of the project:

**Proof-of-concept studies of the electro-migration-enhancement of precipitation**

- Crack in sample (t=100 µm)

120°C, 120 hours (5 days)
Accomplishments to Date

• Long-term (2-week) experiments have been conducted on fractures in reservoir shales under realistic stress, temperature conditions and fluid chemistry
• Time-lapse dataset correlating optical images of fracture aperture distribution, average fracture closure, and fracture permeability (hydraulic aperture) has been obtained.
• Acid treatment of carbonate-rich shale has been shown to reduce proppant crushing by increased surface ductility
• Mineral precipitation from Ca-rich fluid and bi-carbonate additive has been shown to reduce proppant embedment
• Again, the tests revealed very robust, (bi-)linear semi-logarithmic fracture closure deformation behavior with lapse time, for realistic oil & gas reservoir conditions.
Lessons Learned

• Acid treatment of carbonate-rich shale may need to be rather aggressive for having significant impact on proppant survivability

• Ductility reduction of clay-rich shale via mineral precipitation needs to be combined with heterogeneous proppant emplacement to avoid proppant pack clogging

• More effective ductility/proppant embedment reduction requires enhancement of mineral precipitation on and near the fracture surface
Synergy Opportunities

- Field-scale behavior of hydraulic fractures in ductile shale: Collaboration with Tuscaloosa Marine Shale Laboratory (TMSL Consortium/University of Louisiana [PI. Prof. Mehdi Mokhtari]) and Carney Shale Laboratory (Oklahoma State University [PI. Prof. Mileva Radonjic])
- Field-scale behavior of hydraulic fractures in brittle shale: Collaboration with Hydraulic Fracture Testing Site (HFTS)/ Multiscale Modeling Project (MMP)
- Micron-scale shale-proppant interactions: Collaboration with synchrotron X-ray CT imaging of proppant embedment study (LBNL research, M. Voltolini, PI: Matt Reagan [LBNL])
Project Summary

- A new high-temperature & pressure laboratory test system involving in-situ optical visualization technique for shale fracture compaction/ proppant embedment experiment has been developed and demonstrated.

- Correlated datasets of time-lapse proppant crushing/embedment images and fracture deformation and permeability changes for different types of shales have been built.

- Effect of acid dissolution for shale brittleness and proppant crushing reduction for carbonate-rich shale has been demonstrated.

- Effect of controlled mineral precipitation for shale ductility and proppant embedment reduction for clay-rich shale has been demonstrated.
Appendix
Benefit to the Program

Program Goals

• Identify and accelerate development of economically-viable technologies to more effectively locate, characterize, and produce natural gas and oil resources, in an environmentally acceptable manner
• Characterize emerging oil and natural gas accumulations at the resource and reservoir level and publish this information in a manner that supports effective development
• Catalyze the development and demonstration of new technologies and methodologies for limiting the environmental impacts of unconventional oil and natural gas development activities

Project Benefits

This research investigates the possibility of manipulating the sustainability of hydraulic fractures in ductile shales—particularly through alteration of proppant-embedment behavior—using chemical means. If successful, the knowledge gained and technology developed by this project will help economical production of hydrocarbons from normally avoided, resource-rich but difficult-to-develop, ductile shale formations.
Project Overview
Goals and Objectives

The primary objectives of the proposed research are

1. to understand the behavior of fractures in clay-rich, ductile (and sometimes swelling) shales and
2. to begin to develop technologies for efficient and economical production from such shales.

- Fracturing and re-fracturing operation optimization
- Efficient and sustainable oil and gas production
- Development of under-utilized shale resources

Success Criteria
- Demonstrate chemical reaction can be used to modify compaction behavior of proppant/fracture, improving sustainability of hydraulic fractures in ductile shale
- Identify their combinations effective for practical use

Research Activity and Products

(1) Identification of proppant-shale-fluid (P-S-F) combination for proppant embedment behavior in a ductile shale fracture
(2) Laboratory demonstration of the reductions in fracture-closure-induced permeability reduction of a shale fracture
(3) Predictable numerical modeling tool development based upon coupled use of thermal-hydrological-mechanical-chemical codes (TOUGH-FLAC+CRUNCHFLOW)
# Gantt Chart

## Year 1 (Oct. 2018 - Sep. 2019)

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### Tasks

**Task 2: Laboratory experiments**

Subtask 2.1 Acquisition of shale core samples and baseline sample property characterization

Subtask 2.2 Partial modification of the fracture compaction visualization system for THMC experiment

Subtask 2.3 Fabrication of a new fracture compaction visualization cell

Subtask 2.4 Medium-temperature, short-term shale fracture compaction/proppant embedment tests

Subtask 2.5 Preliminary proppant/shale-fluid reaction tests

Subtask 2.6: Higher-temperature, long-term shale fracture compaction/proppant embedment tests

### Subtasks

- **Subtask 2.1**
  - Acquisition of shale core samples and baseline sample property characterization
  - M1

- **Subtask 2.2**
  - Partial modification of the fracture compaction visualization system for THMC experiment
  - M3

- **Subtask 2.3**
  - Fabrication of a new fracture compaction visualization cell
  - M4

- **Subtask 2.4**
  - Medium-temperature, short-term shale fracture compaction/proppant embedment tests
  - M5

- **Subtask 2.5**
  - Preliminary proppant/shale-fluid reaction tests
  - M7, M9, M10

- **Subtask 2.6**
  - Higher-temperature, long-term shale fracture compaction/proppant embedment tests

## Year 2 (Oct. 2019 - Sep. 2020)

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### Tasks

**Task 3: Numerical modeling**

Subtask 3.1 Initial selection of proppant, shale, fluid combinations and THMC model setup

Subtask 3.2 Single indenter/proppant-scale THMC modeling of shale deformation using TREACTMECH

Subtask 3.3 Multi-grain/asperity simulations of proppant-embedment/asperity deformations

Subtask 3.4 THMC modeling of laboratory-observed fracture closure

### Subtasks

- **Subtask 3.1**
  - Initial selection of proppant, shale, fluid combinations and THMC model setup
  - M2

- **Subtask 3.2**
  - Single indenter/proppant-scale THMC modeling of shale deformation using TREACTMECH
  - M6

- **Subtask 3.3**
  - Multi-grain/asperity simulations of proppant-embedment/asperity deformations
  - M8

- **Subtask 3.4**
  - THMC modeling of laboratory-observed fracture closure

## Year 3 (Oct. 2020 - Sep. 2021)

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### Tasks

**Task 2: Laboratory experiments**

Subtask 2.1 Test sample preparation/characterization

Subtask 2.2 High-P/T share-proppant-fluid interaction tests under realistic fluid chemistry

Subtask 2.3 Ductility reduction enhancements via electrokinetic migration of minerals

### Subtasks

- **Subtask 2.1**
  - Test sample preparation/characterization
  - M1

- **Subtask 2.2**
  - High-P/T share-proppant-fluid interaction tests under realistic fluid chemistry
  - M2

- **Subtask 2.3**
  - Ductility reduction enhancements via electrokinetic migration of minerals
  - M5

## Additional Information

- M2 delayed
- M5 completed

Revised: M5 completed for Year-3 project extension.
For the current research project,