A New Framework for Microscopic to Reservoir-Scale Simulation of Hydraulic Fracturing and Production: Testing with Comprehensive Data from HFTS

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Project Update Presentation, August 27, 2019

LBNL - FWP FP00008049, LLNL - FWP FEW0250, NETL - FWP 1022415, SLAC - FWP 10048
Typical Process in Unconventionals Today

- Characterize geology (core/logs/seismic/etc.)
- Design and execute stimulation
- Monitor stimulation
- Produce from well

Trial and Error
Multiple Gaps in Understanding Prevent Predictive Design

- How does characterized geochem/geomech influence frac growth?
- What do geophysical observations really tell us?
- How does micro-scale geochem/geomech influence production of hydrocarbon and waters?
- What is really going on inside proppant packs during production?
- What are implications of fracture swarms for frac growth?
- How does well-to-well interaction affect performance?
- What are implications of fracture swarms for production?
- Characterize geology core/logs/seismic/etc.
- Design and execute stimulation
- Monitor stimulation
- Produce from well

Predictive Design to Enable Adaptive Subsurface Management
Adaptive Subsurface Management Based on Multi-Scale Modeling of Stimulation and Production

Controlling the response of the subsurface to stimulation and production...

A New Framework for Microscopic to Reservoir-Scale Simulation of Hydraulic Fracturing and Production:
Fusing Existing HPC and Experimental Capabilities at DOE’s National Labs
A Multi-Scale Multi-Physics Multi-Lab Project

Linking Two Powerful Simulators to Answer Complex Questions at the Reservoir Scale:
GEOS for Stimulation Behavior, TOUGH for Production

GEOS ← TOUGH

New Constitutive Models for Shale Property Evolution from Geomechanics and Reactions Based on Micro-scale and Core-Scale Experiments and Simulations
Reservoir Simulations

- HFTS data analysis and model preparations
- Initial “top-down” stimulation modeling with GEOS
- Development of new upscaling techniques
- Coupling between GEOS and TOUGH
- Preliminary production simulations with TOUGH
Hydraulic Fracturing Test Site (HFTS)

- Over 240 GB, hosted in an EDX Workspace
- Raw geophysical logs
- Fiber-based temperature data
- Extensive microseismic catalog
- Production and tracer data
- Multitude of reports and presentations
- Special thanks to GTI for facilitating access and navigating the dataset!

See Presentation by Jordan Ciezobka tomorrow 8 am, Ballroom B
Preliminary GEOS Models Have Been Built That Match Microseismic

These models use a “top-down” approach to match observed behavior (e.g.: tuning leak-off)
Upscaling of Stress Heterogeneity and Fracture Swarms

How does characterized geochem/geomech influence frac growth?

What are implications of fracture swarms for frac growth?

New upscaling concepts show promise for predictive modeling
Workflow for Production Simulations with TOUGH+

Hybrid MINC Modeling for Efficient Reservoir Simulations:
- Large-scale fractures simulated as discrete features in model domain
- Smaller fractures simulated as secondary fracture continuum
- Shale matrix simulated as multi-continuum
Coupling Between GEOS and TOUGH: We Have Developed and Demonstrated an Initial Coupling Method

- Geological data (velocity, stress, DFN, permeability)

Next steps:
- Perform further validation of the mapping between GEOS and TOUGH+
- Increase complexity of the GEOS models that are mapped to TOUGH+
Designing and Testing Coupling Method Between GEOS and TOUGH

Discretization?

TOUGH Mesh
(Connectivity)
Micro-scale Experiments and Modeling

• Micro-mechanical investigations of proppant/shale interactions
• Micro-scale reactions, chemical alterations, and impact on fracture/matrix properties
Micro-scale Experiments/Modeling to Inform Reservoir-Scale Models

GEOS  TOUGH

New Constitutive Models for Shale Property Evolution from Geomechanics and Reactions Based on Micro-scale and Core-Scale Experiments and Simulations
Micro-scale Experiments/Modeling to Inform Reservoir-Scale Models

New Constitutive Models for Shale Property Evolution from Geomechanics and Reactions Based on Micro-scale and Core-Scale Experiments and Simulations

Need a workflow and relationships that work over a broad range of conditions (Phase I: Marcellus, Phase II: Wolfcamp)
Understanding Proppant/Shale Interaction: Experiments at Grain and Monolayer Scale

- Microscale provides single proppant grain/shale interaction information
- Mesoscale allows handling of partial and whole monolayers

**Micro (proppant grain)- scale**
*Indentation experiments*

**Sub-monolayer (small continuum)-scale**
*Indentation experiments*

- Brittle Marcellus shale (from outcrop)
- Ductile Marcellus shale (MSEEL)

T=0/196 psi T=31 days
T=0/3984 psi T=15 days

- Crushed proppant grains
- Heaved shale matrix

What is really going on inside proppant packs during production?

Mini-triaxial cell for synchrotron X-ray micro Computed Tomography (SXR-microCT) at ALS

Closure experiment with fluorescent visualization
Micro-scale to Meso-scale Fracturing and Proppant Mechanics

Data from indentation experiments can be used to model the evolution of physical properties of the sample, e.g. permeability, or flow resistance.

Micro-scale Observations/Measurements

Meso-scale Observations/Measurements

Next step is to do the same experiments on HFTS core
Impact of Micro-scale Reactions on Fracture and Matrix Permeability

SLAC: Characterization of shale matrix pre- and post-injection

NETL: Fracture flow experiments

BLNL: Pore- and continuum-scale modeling

Deliverables:
Constitutive laws that describe permeability and diffusivity evolution due to coupled physical-chemical alteration, especially at the matrix-fracture interface

\[ k = f(k_0, Q, pH, C_i, t \ldots) \]

to be applied at reservoir scale to inform fracturing and production simulations

Experimental conditions relevant to the field practice (e.g. pH and salinity across the stimulated rock volume), and samples from the test site.
Fracture Flow Experiments

Research question: How does reactive flow influence fracture alteration?

Major activities:

• Focus on fracture alteration driven by reactive flow pathway
• Controlled core flood experiments relate reactive flow in fractures to fracture permeability and matrix changes
• Fe chemistry is clearly controlled by reactive flow conditions
• Next step is to do experiments on HFTS core
Matrix Alteration

**Research question:** How does the altered zone forming at the fracture-matrix interface evolve over time?

**Major activities:**

- Focus on matrix alteration driven by fluid chemistry
- Time-lapse reactors cover *wide* range of time steps & chemical conditions
- Characterization of reacted cores and fluids shows that:
  - Fe(III)-oxide scale rim thickens over time in spite of persistent acidic conditions (first time observed!)
  - K/Fe co-accumulation not observed before; Fe-rich *clay mineral scale* precipitated (first time observed!)
- Next step is to relate results matrix alterations to changes in porosity and permeability (using HFTS core)
Accomplishments to Date

• Built an integrated multi-lab, multi-scale project team
• Developed initial stimulation and production models and demonstrated efficient GEOS-TOUGH coupling
• Developed upscaling approaches for stress structure and fracture swarms
• Conducted workflows for testing shale/proppant behavior and how this can be accounted for in reservoir models
• Established frameworks for integrated investigation of shale alteration due to interactions with fracturing fluids

Next Steps

• Conduct experiments on HFTS core and develop upscaling relationships
• Perform final stimulation and production simulations

Lessons Learned

• Access to data and core is a process of unpredictable length
Synergy Opportunities

• HPC simulators GEOS and TOUGH have been developed with DOE resources across multiple DOE programs, from SC-BES to geothermal to nuclear waste, and NNSA

• Micro-scale experimental and simulation work is closely aligned with several fundamental shale research projects across national labs
  - See special session on “National Lab Fundamental Shale Research”, Rooms 301-302, Monday 4 pm

• New modeling framework can be applied to other DOE-funded field test sites for unconventional oil and gas, e.g.
  - Tuscaloosa Marine Shale Laboratory (Ballroom B, Tuesday 10:30 am)
  - Marcellus Shale Energy and Environment Laboratory (Ballroom B, Tuesday 11:00 am)
  - Eagle Ford Shale Laboratory (Ballroom B, Wednesday 8:30 am)
  - Hydraulic Fracturing Field Test Site II (Ballroom B, Wednesday 9:00 am)
  - …

• New modeling framework can be used to provide a better predictive understanding of stimulation and production processes in various industry projects
Project Partners

Funding and Project Management

U.S. DEPARTMENT OF ENERGY  
NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

Research

BERKELEY LAB  

SLAC  
NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

HFTS Collaboration

gti® GAS TECHNOLOGY INSTITUTE and various other HFTS I consortium partners
Using the HFTS Opportunity to...

- Validate DOE’s high-performance computational capabilities for fracturing and production against a unique high-quality field and lab data set
- Develop a framework for reservoir simulations informed by micro-scale processes for adaptive subsurface management
- Develop a better predictive understanding of fracturing processes in tight shale
- Develop a better predictive understanding of production processes as impacted by detailed fracture-characteristics and micro-scale transport
Benefits to the Program

• Allows the program to benefit from combined investments across multiple labs and multiple programs
• Helps draw additional value from the HFTS investment
• Developing new concepts that can be readily transferred to industry
  • Rigorous upscaled approaches for integration into fast-running tools
  • New insights into fracturing fluid-formation compatibility
Organization Chart

Project Leadership:
Co-Leads: Jens Birkholzer, LBNL; Joe Morris, LLNL

Project Management: Multi-Lab Leadership Team

Task 1: Reservoir Scale
Joe Morris, LLNL; George Moridis, LBNL

Subtask 1.1: HFTS Data Assessment
Lead: Joe Morris, LLNL
Participating Lab POCs: George Moridis, LBNL

Subtask 1.2: Hydraulic Fracturing Simulations
Lead: Pengcheng Fu, LLNL
Participating Lab POCs: George Moridis, LBNL

Subtask 1.3: Production Simulations
Lead: Matt Reagan, LBNL
Participating Lab POCs: Yue Hao, LLNL

Subtask 1.4: Coupling Methodologies
Lead: George Moridis, LBNL
Participating Lab POCs: Randy Settgast, LLNL

Task 2: Micro Scale
Carl Steefel (LBNL); Joe Morris (LLNL)

Subtask 2.1: Micro-scale Mechanics
Leads: Randy Settgast and Joe Morris, LLNL
Participating Lab POCs: Tim Kneafsey, LBNL

Subtask 2.2: Micro-scale Reactions
Lead: Hang Deng, LBNL
Participating Lab POCs: C. Lopano, NETL; J. Bargar, SLAC; Y. Hao, LLNL

Subtask 2.3: Core-Scale Validation
Lead: Matt Reagan, LBNL
Participating Lab POCs: Dustin Crandall, NETL; Yue Hao, LLNL

Subtask 2.4: Upscaling Micro- to Continuum
Leads: Matt Reagan, LBNL
Participating Lab POCs: Randy Settgast, Joe Morris, LLNL

Multi-Lab Leadership Team: Comprises PI's, Task and Sub-Task Leads, and Lab POCs
Bibliography