Mechanistic Approach to Analyzing and Improving Unconventional Hydrocarbon Production

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Overcoming Barriers to Production Delivering Basin-Specific Optimization Strategies

- Previous 5 years: Our platform for unconventional shale can predict pressure dependent gas production at the MSEEL-1 site making optimization possible.
- Next year: We will extend our approach to other DOE field sites (e.g. HFTS, Baaken) and continue to disseminate our results to industry (e.g. Chevron, Apache).



Barriers to Production

- Premature closure of the stimulated reservoir volume
 - Aggressive drawdown practices -> Learn to manage pressure to optimize production (LANL work)
 - Incompatible chemistry fouling fracture and matrix communication -> Tailor the working fluid to prevent fouling in fractures and matrix (e.g. SLAC work)



Time

Aggressive pressure drawdown can close off parts of the reservoir



Barium carbonate fouls a fracture network In a Los Alamos experiment

Use case: Pressure Management

Slower drawdown can increase total recovery, but at the expense of reducing near term recovery.





- Slower drawdown rates can lead to improved recovery efficiency in gas production from shale
 - > Anecdotal evidence from field experiences
 - Chemical signatures, consistent with known physical mechanisms
 - > Recent simulation case studies showing effect
- Yet, slower drawdown requires an operator to forego high near-term production for higher overall production.
 - > Uncertain site-specific characteristics/behavior (risk)
 - > Unquantified **benefit**

A Mechanistic Reservoir Simulation Tool for Unconventional Reservoirs

Strategy: Develop a platform for an operator to optimize site-specific recovery of hydrocarbon (initially, gas), based on a combination of accurate site-specific synthetic data and real field data (when available).



Physical behavior of system described as a combination of fracture transport and matrix-scale transport

 Theoretical development and experimental characterization occurring through FE-30 investments

Fast, accurate reservoir-scale simulations using discrete-fracture network platform in combination with graph-based models & machine learning

- Initial development with LDRD
- Extension to gas in shales through FE-30

Ultimate goal—Scientifically based reservoir management strategies (and associated toolsets) for increasing recovery efficiency from shale.



Matrix Controls on Production:

We are developing an accurate, site- (or basin-) specific predictive model for transport of gas through shale matrix: Rate = $C \cdot D \cdot \Delta P$

We determined that matrix damage can occur at high ΔP This impacts rate of production (*C* and *D*) And is a Function of Reservoir History



Matrix Controls on Production:

We are developing an accurate, site- (or basin-) specific predictive model for transport of gas through shale matrix: Rate = $C \cdot D \cdot \Delta P$

Impact of barite precipitation on matrix porosity Collaboration with SLAC using small angle neutron scattering



- SANS experiments on Marcellus and Eagle Ford shales following reaction with barite promoting fluids
- Both shales lost ~14% of their porosity due to barite precipitation
- Marcellus shale loses most porosity at ~2.2 nm
- Eagle Ford shale loses porosity more uniformly

Matrix Controls on Production:

We are developing an accurate, site- (or basin-) specific predictive model for transport of gas through shale matrix: Rate = $C \cdot D \cdot \Delta P$

Analysis of kerogen pore structure Collaboration with SNL using small angle neutron scattering



- Differentiates between pores occurring in kerogen and clay
- Provides insight on the maturity of the shale (gas rich, oil rich)
- Discovered kerogen pore sizes range from 1-5 nm which SANS can interrogate but are below resolution of most methods

Tributary Fracture Controls on Production We are developing an accurate, site- (or basin-) specific predictive model for fracture transport: $k_{eff} = b^2/12$, where $b = b_0 \cdot \exp[a \cdot \sigma_n]$

Developed & validated scalable, pressure dependent model for fracture aperture (*b*) based on experiments on MSEEL core



Tributary Fracture Controls on Production We are developing an accurate, site- (or basin-) specific predictive model for fracture transport: $k_{eff} = b^2/12$, where $b = b_0 \cdot \exp[a \cdot \sigma_n]$

Created Reduced-Order Model to investigate drawdown conditions Using experimental data, we identified potential critical drawdown conditions that can close fractures→MSEEL core may be near critical stress



dfnWorks:

Fast, Accurate Simulations of Unconventional Reservoir Performance

Incorporated detailed mechanisms based on experimental data for fracture & matrix into dfnWorks





Year	1	2	5	10
% Fracture Production	99	95	75	40
% Matrix Production	1	5	25	60

Fast, Accurate Simulations of Unconventional Reservoir Performance Fracture closure as a function of drawdown strategies at MSEEL-1

- Simulation of the impact of pressure drawdown on complex fracture networks
- Utilizes Barton-Bandis model for aperture changes due to changing fluid pressure
- Results based on experimentally measured parameters

Low drawdown strategy: more contribution from entire fracture network High drawdown strategy: less contribution from entire fracture network Production for different drawdown scenarios



DOE's Hydraulic Fracture Program Addresses Key Features of Production Curve Providing Path to Improved Recovery



FY21 Proposed Work: Other basins and 2nd order effects for Pressure Management in Gas-Dominated Systems

- Apply pressure management strategy beyond the Marcellus to other DOE field sites such as HFTS and Baaken sites
 - Experimental characterization of pressure sensitivity of nanopore system
 - Experimental measurements of pressure sensitivity of fractures
 - Numerical tool development for optimizing productivity
- Incorporate geochemical mechanisms impacting permeability and production into unconventional reservoir platform
 - Measure the impact of geochemical processes (e.g. barite precipitation) on nanopore structure and hydrocarbon transport in shale matrix using SANS experiments and LBM simulations
 - Experimental study of barite precipitation in dynamically fractured core: impact on matrix-fracture communication
- Integrate pricing models (net present value, capital costs, hydrocarbon prices, etc.) with reservoir optimization tool to develop efficient economical analyses

Goals for our Research Program

- FY25: Industry broadly adopts the new DOE approach
- FY24: Platform is commercialized and/or licensed
- FY22-24: Industry gains confidence in the approach through multiple field-validation tests
- FY 21: Platform is tested on other basins to demonstrate robustness of the approach