Integration of Microseismic, Production Data and Numerical Simulation to Evaluate Uncertainties in Unconventional Reservoirs. What is the Impact on Estimated Ultimate Recovery?

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Outline

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Background
Background

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Williston Basin

Project Area
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Background

Little Knife Anticline

Project Well
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Background
Background

- DEM of Area
- 2 Directions of Surface Lineaments inferred to be related to Basement Faulting
- Surface and Subsurface Data Suggests a Diverse Natural Fracture Population Across the Location.
- Lower Angle Shear Fractures related to Basement Faulting
- High Angle Type I Regional Extension Fractures (small aperture)

FMI Rose from TRD Thomas 4-1H (~15 mi NW)
Background

Gas shows are inferred to be related to natural fracture swarms.
Background

Early multistage,
Generation II,
completion

Eight Ball/Sleeve Stages:
Job Type Slickwater
BORAjel-5
Sliding Sleeves: 11,400’ – 19,861’
Max Slurry Rate: 56.1 bpm
Avg. Slurry Rate: 37.9 bpm
Max Pressure: 6,382 psi
Avg. Pressure: 5,919 psi
20/40 Ottawa: 351,000 lbs.
20/40 Super L/C: 94,800 lbs
Fluid: 17,688 bbls.
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Objectives
Objectives
To understand the impact of “seismic event window” on dynamic calibration and EUR predictions
To understand the impact of “assumptions in DFN generation” on dynamic calibration and EUR predictions
To understand the impact of additional wells on NPV and EUR
Objectives

To understand the impact of “seismic event window” on dynamic calibration and EUR predictions

To understand the impact of “assumptions in DFN generation” on dynamic calibration and EUR predictions

To understand impact of additional wells on NPV and EUR

This presentation focuses on the second objective
Available Data
Available Data

Drilling - vertical and horizontal wells
  Mud log, gas chromatography
Cores from nearby wells
  Porosity, permeability, capillary pressure
Electric logs from the vertical well
  Stratigraphy, NTG, porosity, ~water saturation
Hydraulic fracturing operation
  Injection pressure, injection volume, microseismic
Production operation
  Oil, gas and water volumes, flowing THP
Interpretations and Assumptions
Interpretations and Assumptions

Microseismic Events Monitored during the Completion are used as seed loci for Stochastic DFN Generation

Aperture and Connectivity are linked to Event Amplitude and Distribution
Interpretations and Assumptions

Wellbore Pseudo Fractures – White

FMI/Lineament Fractures – Purple/Blue

Hydraulic Fracture Network - Green
Interpretations and Assumptions

Only simulated fractures actually coincident with the wellbore or connected to the wellbore through adjacent fractures are shown.
Interpretations and Assumptions

Discrete Fracture Network is upscaled to delineate the Stimulated Rock Volume (SRV) distribution, connectivity and associated permeability.
Interpretations and Assumptions

In this presentation we compare 2 DFN Models

Model #1 has one fracture set, with strike parallel to the main axis and limited scatter in the strike orientation.

Model #2 has two intersecting fracture sets with one parallel to the main axis and other having strike of 80 degrees with significant amount of scatter.

Both models were upscaled for porosity, permeability and sigma array associated with the hydraulic fracture
Larger Connected SRV estimated for Model #2
Interpretations and Assumptions

Effective porosity of bounding shales = 1%
Dolomite matrix porosity = 6.5%
Dolomite matrix permeability = 0.010 mD

Single water-oil matrix drainage capillary pressure curve that corresponds to 6.5% porosity
Zero capillary pressure in the fractures
Straight line water-oil matrix/fracture relative permeability curves
Interpretations and Assumptions

Pc Drainage (oil-water)
Uncertain Parameters of the Analysis
Uncertain Parameters of the Analysis

– Initial reservoir pressure
  • 72-hour buildup shows minimum of 5200 psia

– Initial matrix water saturation
  • set through depth of pseudo WOC

– Water-oil relative permeability scaling
  • Krw left constant and Kro is scaled
Uncertain Parameters of the Analysis

- Vertical communication among the layers
  - Intercalated shale streaks
- Permeability of the natural fractures
  - Assume uniform value
- Porosity of the natural fractures
  - Assume uniform value
- Sigma for the natural fractures/matrix
  - Assume uniform value
Uncertain Parameters of the Analysis

– Amplitude of HF permeability distribution
  • Use multiplier to upscaled DFN values

– Amplitude of HF porosity distribution
  • Use multiplier to upscaled DFN values

– Amplitude of HF based sigma distribution
  • Use multiplier to upscaled DFN values

– Connection % of HF to the wellbore
  • Use well PI (or WI) multiplier
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Dynamic Calibration Process and Results
Unstable early THP data

Installation of artificial lift

Reliable THP
Reliable water production

Flow back of HF fluids
Dynamic Calibration Process and Results

DFN Model #1

In-house Assisted History Matching Software
11 history matching parameters
Experimental design for coverage of range
ANN and Genetic Algorithm for global search
Response Surface and GA for optimization

Runs ~15 minutes - maximum 5-day time steps
Approximately 170 simulation runs
Excellent match of THP data

Excellent match of water data
The difference in water production is 8000 barrels. This indicates that 44% of the fracturing fluid was recovered.
Dynamic Calibration Process and Results

DFN Model #2

In-house Assisted History Matching Software

11 history matching parameters

Experimental design for coverage of range

ANN and Genetic Algorithm for global search

Response Surface and GA for optimization

Runs ~15 minutes - maximum 5-day time steps

Approximately 240 simulation runs
Average match of THP data

Excellent match of water data
Dynamic Calibration Process and Results

Pinit \quad WOC
Krocw \quad KzfMult
WPImult

NFKadd \quad HFKmult
NFPadd \quad HFPmult
NFSadd \quad HFSmult
Simulation Parameter Radar Plot

Top 20 solutions for DFN Model #1

Parameters:
- Klocw
- WPIMULT
- Pinit
- HFPmult
- HFKmult
- HFSmult
- WVOC
- NFSadd
- NFKadd
- KZFmult
- NFPadd
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Dynamic Calibration Process and Results
Uncertain parameters for best solutions

Best solutions are especially different in NF Permeability values
Dynamic Calibration Process and Results

Fracture delta P at 6/2010 for both DFN Models

Filtered at minimum fracture delta P of -500 psi
Dynamic Calibration Process and Results

Matrix delta P at 6/2010 for both DFN Models

Filtered at minimum fracture delta P of -500 psi
Dynamic Calibration Process and Results
Matrix delta P at 6/2010 for both DFN Models

Filtered at minimum matrix delta P of -500 psi
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Predictions and Sensitivity Analyses
Predictions and Sensitivity Analyses

Response surface + Monte Carlo: 100 solutions

Classified 100 solutions into 5 clusters

For each DFN model:
  Repeated five history match runs
  Performed five predictions into the future
  Each prediction has different probability

Kept the flowing BHP at 6/2010 values
5 clustered solutions for DFN Model #2
For DFN Model #1 oil recovery range at 50 years is 340 to 360 MSTB.
Predictions and Sensitivity Analyses
Performance of DFN Models #1 and #2

16% Difference in 50-year Oil Recovery Estimates
Significant Difference in Predicted Water Cut Profile
Integration of Microseismic, Production Data and Numerical Simulation to Evaluate Uncertainties in Unconventional Reservoirs.

What is the Impact on Estimated Ultimate Recovery?

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