Hydraulic Fracturing Theory & Practice

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What is Hydraulic Fracturing?

Pad

Proppant Slurry
GOALS: Hydraulic Fracture Stimulation

- Maximize hydraulic frac length
- Achieve finite (non-zero) conductivity
- Minimize treatment cost
- Minimize conductivity damage
- Minimize damage to the formation
- Maximize number of zones producing
- Drain everything connected to the well
- Accelerate recovery & add reserves
McGuire-Sikora Folds-of-Increase Curves for Pseudo-Steady Flow

\[ RC = \frac{k_f w_f}{k} \sqrt{\frac{40}{A}} \]

\[ SR = \frac{J}{J_o} \left( \frac{7.13}{\ln(0.472 \frac{r_e}{r_w})} \right) \]

0 2 4 6 8 10 12 14

0 1000000 100000 10000 1000 100

Relative Conductivity, inches

Stimulation Ratio

L/r_e

0.1 0.2 0.3 0.4 0.6 0.8 1.0
Well Performance: Setting the Benchmark

- Pressure buildup analysis
  - lose or defer production
  - must wait for well to clean-up
  - takes ‘forever’ to reach radial flow
- Production performance analysis
  - long flow times
  - takes ‘forever’ to reach flow boundaries
  - lots of data to archive
- Decline curve (Arps) Analysis: Beware of exponents >1
  - still in transient flow
  - not volumetric reservoir performance
  - decline curves are not valid
Fractured Well Performance
Actual vs. Expected

- 200,000 lb frac
  - Created $X_f > 1000'$
  - $k = 0.15$ md
  - Effective $X_f = 20$
  - OGIP = 10 BCF

- $X_f = 300'$, $K_iW_i = 1000$ md-ft
- $X_f = 1000'$, APC < 1 lb/ft²
- $X_f = 20'$, $K_iW_i = \text{infinite}$
Business Case for Frac Improvement

• Assumptions:
  – Single Well, Total Depth 8500’
  – Net pay thickness = 50 feet
  – Average effective permeability = 0.15 md.
  – Drilling and Completion per Well: $1.4 mm
  – Fracture Stimulation: $80,000
  – Gas Price $6.50/mcf
  – Current Effective Fracture Half Length Xf= 20’

• Evaluate impact of an increase in effective length to 300’ or 600’ with proper design and formation characterization
Gas Rate Decline: Stimulated Wells

Infinite conductivity $X_f$:
- $X_f=600'$
- $X_f=300'$
- $X_f=20'$, Actual Well
- $X_f=0$, Skin=+5
Cumulative Production: Stimulated Wells

Estimated Cumulative Production

Infinite conductivity $X_f$:
- $X_f=600'$
- $X_f=300'$
- $X_f=20'$, Actual Well
- $X_f=0$, Skin=$+5$

0.75 BCF Incremental
Business Case Economic Analysis

Base case economics – first 3 years production

– Fracture half-length increased from 20’ to 300’
  • Incremental NPV@20% $6.5 MM per well

– Fracture half-length increased from 20’ to 600’
  • Incremental NPV@20% >$10.0 MM per well
Find & Fix the Problem

• Why is current Xf = 20’?
• Can a longer length be achieved?
• What must be changed to improve performance?
• Can treatment cost be decreased without loss of production?
The Challenges

- Frac geometry
  - not creating expected length
  - growth out of zone
- Proppant transport
  - prop falling out of zone
  - prop pack not connected to perfs
- Final conductivity
  - gel damage; breaker/clean-up issues
  - proppant crushing; non-Darcy flow
- Reservoir properties
  - Kh isn’t what you expected
  - Drainage area less than desired
What do we need to know to ...

- Define the problem
- Benchmark our performance
- Decide what to change
- Generate realistic expectations
- Optimize completion/stimulation
- Get what we want or what we should expect from our wells
Good Results Come From

• Adequate reservoir characterization
• Accurate design models
• Pre-frac diagnostics
• Post-job analysis