A Methodology for Evaluating Economic Refracturing Candidates and Optimizing Refracture Treatments*

Robert Barba

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Refracturing Background

Numerous well performance studies:
- Significant reserves remain in existing well bores.
- Infill wells can be marginally economic in a low gas price environment.
- Refracturing can be an economical alternative to new well drilling to access these reserves.

Conclusions

- If remaining producible gas reserves can be accessed with refracs the economics can be attractive even at low gas prices
- The candidate selection and treatment execution steps are relatively straightforward and use off-the-shelf hardware and software
- The techniques have the potential to significantly improve the success rate and economics of refracture treatments

References


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AAPG New Ways to Look at Old Data
November 8, 2010
Refracturing Background

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  - Infill wells can be marginally economic in a low gas price environment
  - Refracturing can be an economical alternative to new well drilling to access these reserves
Why Are the Hydrocarbons Still There?

- Many opportunities are the result of assuming fracs are “reserve-seeking missiles”
- It is common knowledge that fracs “work”
- “How fracs work” is not as well understood
Refrac Opportunities

- Wells with:
  - Multiple perforation clusters in single frac stages
  - Poor fluid selection
    - Water-based fluids in sub-irreducible reservoirs susceptible to capillary phase trapping
    - High-viscosity fluids where complexity needed
  - Poor proppant selection
  - Inadequate proppant volumes
Multiple Perf Clusters Single Stage

PLT  Effective Frac Length

452 MCFD  0 ft (+5 skin)

136 MCFD  1 ft (0 skin)

135 MCFD  420 ft

20 acre offset upper zone
6 MMCFD
Multiple vs Single Perf Clusters

Multiple Perf Clusters

Apparent Frac Length

254 ft  264 ft

Single Perf Cluster

One cluster in multiple batch performs identical to single cluster
Remaining zones skin removal
Sub-Irreducible BVW

Morrow SE New Mexico
Highly susceptible to capillary phase trapping

BVW 2.5%
BVI 5%
Sub-Irreducible Sw Frac Performance

- Median CO2 Assists: 107%
- Median Stable foams: 108%
- Median XLG: 39%
- Median Clearfrac: 33%
### Sub-Irreducible Sw Field Papers

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<th>SPE</th>
<th>Year</th>
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<td>67212</td>
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**Total**

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<tr>
<td>XL</td>
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<tr>
<td>Foams</td>
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All of the above studies used production results only  
Not normalized to formation permeability and pressure
Slickwater refrac of Barnett vertical well originally fracced with crosslinked system

Original paper SPE 108817
Recent paper (Florence Sept 2010) good update on worldwide refracs
Over 100 case studies detailed in paper
Refrac Optimization Process
Flow Chart

Evaluate Candidate Well and Zone Performance

Pressure Test Each Zone

Isolate Economic Zones and Refrac
Why Poor Initial Well Performance?

- Low permeability-thickness?
- Low reservoir pressure?
- An inefficient stimulation?
- All of the above?
Performance Analysis Techniques

1. Completion Efficiency
2. Apparent frac length
3. Recovery factor
4. Production analysis
CE Process Flow Chart

1. Measured Permeability
   - Correlate to Openhole Logs

2. Measured Pressure
   - Correlate to Pre-frac pump-in

Production Forecast
Minimum Frac Length and Conductivity for Drainage

Compare to actual Production

Completion Efficiency
Actual Rate/Minimum Rate
Completion Efficiency Concept

660 ft for 40 ac spacing

90% = 600 ft $X_f$

CE 100% if actual rate = rate with 600 ft infinite conductivity frac
Absolute minimum-elliptical drainage not square
CE Model Permeability Calibration

- Field $kh$ from pressure transient test or flow test
- $Kh$ using Coates-Denoo model:
  - $Kh = \sum [(C \Phi^2 (\Phi - B_{vw})/B_{vw})]^2$
  - Vary “C” until $kh$=field $kh$
- Used worldwide with excellent results
Well A was a multiple zone well test

Coates-Denoo “C” = 6.5
Well Test
CE Model Pressure Calibration

- Measured reservoir pressure vs pre-frac pump in test closure and/or ISIP
- Use pre-frac pump-in test results to estimate pressure at time of completion
DFIT Pressure Profile

Small volume pumped enough to initiate a fracture
Measured Reservoir Pressure vs Closure Pressure

\[ y = 1.3261x - 0.4688 \]

\[ R^2 = 0.9161 \]

Reservoir Pressure Gradient psi/ft

Closure Stress Gradient psi/ft TVD

SPE 90483
Measured Reservoir Pressure vs Frac Gradient

\[ y = 1.6012x - 0.7846 \]

\[ R^2 = 0.944 \]
2. Apparent Frac Length

- Vary $X_f$ until model = actual rate
- Assume infinite conductivity
- Not true $X_f$ - conductivity rarely infinite
- Qualitative frac efficiency index to compare relative performance

SPE 90483 and others
CE vs Apparent Frac Length

Completion Efficiency
40 acre spacing 600 ft $X_f$ minimum/200 mdft conductivity

Apparent Frac Length ft

Completion Efficiency
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
3. Recovery Factor (RF)

- Estimate ultimate recovery from:
  - Decline curve
  - Rate vs cum production
  - Rate/transient
  - P/Z

- Estimate GIP for proration unit/fault block

- RF = EUR/GIP or EUR/OIP

SPE 90483 and others
Recovery Factor Flow Chart

Porosity, Sw, h from Openhole Logs → Pressure from ISIP Correlation

Area of Proration Unit or Fault Block

Gas or Oil in place at Completion

EUR Oil or Gas

Recovery Factor EUR/OGIP or EUR/OOIP
4. Production Analysis

- RPI or rate-transient analysis
- Good for well performance and EURs
- Multiple zone performance-limited
- Results typically consistent with CE and RF
- Linear flow analysis useful for gas shales

SPE 37409 (Crafton 1997) (RPI)
Fetkovich (1980) (rate-transient type curve analysis)
Key Refrac Candidate Issues

- What zones contain the remaining producible hydrocarbons?
- How are the hydrocarbons distributed?
  - Petrophysical analysis combined with PLT
- What is the current reservoir pressure in each zone?
  - Where did the primary fracture go?
  - What is left in the secondary zones?
Zonal Pressure Testing Hardware
Injection Testing Pressure Response

QC data with log-log plot to determine radial flow
Small volume pump-ins do not require type curve analysis
Zonal Pressure Testing

- Existing perforated intervals can be straddled with assembly and pressures obtained from static buildup and/or injection/falloff testing (DFIT or diagnostic fracture injection test)
- Over 60 tests successfully executed to date using hardware described
- System displayed used surface readout and downhole shut-in
- Can use memory gauges
Zonal Pressure Testing Example

QC data with log-log plot to determine radial flow
Small volume pump-ins do not require type curve analysis
Zonal Pressure Testing Example

Time (Seconds)
Static buildup pressure using downhole shut-in gives minimum pressure
Key Refrac Candidate Issues

- How do you access the remaining producible reserves with a refrac?
  - Frac all existing perfs together?
    - “Eastwood” frac
  - How do you frac below existing perfs?
Multiple Zone Scenario

Original Completion

Refrac

“Eastwood” frac goes where gas was
Refrac Options Below Existing Perfs

- Packer and bridge plug
  - Get proppant above packer—often problematic
- Coiled tubing
  - Limited to treatment down tubing
- Metal liners
- Casing patches (Pengo/Owen)
- Openhole swell packers
- Openhole mechanical packers (preferred)
Mechanical Packer Example
### Mechanical Packer Vertical Well Refracs as of Q2 2009 (2 Vendors)

<table>
<thead>
<tr>
<th>Location</th>
<th>Formation</th>
<th>Size of Tools</th>
<th># Stages</th>
<th>Type of Stim. System</th>
<th>Fractional Information</th>
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<td>Lipscomb County, TX</td>
<td>Cleveland Sand</td>
<td>4-1/2&quot; x 2-7/8&quot;</td>
<td>4</td>
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**Formation Table:**

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<tr>
<th>Formation</th>
<th>Casing</th>
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