Refrac Developments and Challenges
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Are We At This Point With Refracs?

“The researches of many commentators have already thrown much darkness on this subject, and it is probable that, if they continue, we shall soon know nothing at all about it.”

– attributed to Mark Twain

What is Our Stimulation Objective?

30,000 ft View:
• Maximize well value through optimized stimulations (hydraulic fracturing, HF)

A Little Deeper:
• Optimize fracture surface area and fracture conductivity

Deeper Still:
• Optimize fracture creation vs. natural fracture access (leakoff control); maintain access (proppant placement); and optimize HF flow capacity (proppant placement and conductivity)
Defining a Refrac Candidate

A refrac candidate is any well that can economically be restimulated, meaning:
1. The well has previously been stimulated; and
2. All the conditions necessary to meet a company’s economic metric – including environmental and safety issues – can be met through either an acceleration of production or an increase in recoverable reserves.

Refrac’s are not new technology and have essentially been used since the beginning of commercial hydraulic fracturing operations in 1949

The Kuparuk Case History

Historically, the ARCO work on the Kuparuk River Unit on the Alaskan North Slope is one of, if not the, seminal effort regarding refracturing applications and design (from 1987 to 1992).

The critical conclusions included:
1. “Fracture design enhancements can provide strong rate incentives to refracture wells using improved technology.”
2. “Stimulating high productivity wells can yield substantial incremental rates due to increases in flow efficiency and kh.”
3. “Refracture treatments may increase net pay in communication with the well to increase oil recovery.”
4. “Increased fracture conductivity allows greater benefits from larger job sizes.”

The Kuparuk Lessons

The ARCO work on the Kuparuk River Unit provided key lessons about when to consider refracturing:
1. Technology has improved such that utilizing improved stimulation technology will add well value (i.e., this new technology allows the frac to reach rock with higher-than-producing BHP in spite of a good original stimulation); or
2. The original stimulation was sub-optimal (known damage, over-flushed, etc.) meaning that the original stimulation itself is not infinite conductivity; and
3. The best refrac candidate is not necessarily the poorest performer.....
The Kuparuk Lessons

The AF about:
1. Technical factors:
   - Ineffective or problematic initial completions
   - Unstimulated horizons
   - Low fracture conductivity
   - Short fracture length
   - High skin, or damage

2. The reservoir factors:
   - N-structure, not reservoir storage
   - Inertial interference of nearby wells
   - Extreme, multifractured reservoir itself

3. The production factors:
   - Technology evolution
   - Advanced stimulation technology
   - New completion techniques
   - Well age

Well underperformance

What Are The Economics of Refracs

Much is made about the present-day economics about refracs:

"Compared to drilling and completion costs for a new well, refracturing can be significantly cheaper (about $2 million), while recovering as much as 1 Bcf of incremental gas reserves. In fact, refracks often provide such a high return on investment that it is recommended that refrack planning be part of the initial development of a field," according to a recent Drillinginfo report. [E&P Magazine is Refracking An Economic Alternative, July 25, 2017]

Economics Favor Refracs Of Horizontal Wells in Unconventional Plays

By George E. King

World Oil

Refraacting immediately increases gas rate 700% and sustains 400% increase for three months in Haynesville shale well

A Better Economic View of Refracs?

Does this suggest, taken to its extreme, that we should intentionally under-stimulate the original well with the purposeful intention of refrac'ing the well?

Or:

Is the bulk of the reason we embark on a refrac campaign is because we know (or significantly suspect) that significant hydrocarbon has been left behind pipe.

Fundamentally, then, this means the original stimulation was not optimal — and this needs to be admitted (and, furthermore, refracs should be viewed as a "bad" thing such that their success serves as motivation to improve current and future original stimulations).
Other Views on Refracs

"The technology is not ready for prime time," said Chris Robart, a director at energy consultancy IHS. "The challenge is in identifying candidates for refracs, and deciding how to refracl the well, are not that simple. There's a lot of gaps in data that need to be there to make good decisions about how to design a refrac operation."

Robart said refrac operations can be "pricey" unless well bores are designed in a way to facilitate them. And re-fracking doesn't fit the "highly efficient, manufacturing mobile factory model" of shale wells, he said.

Others say there is no easy way to ensure the refrac treatment will go to the left-behind parts of the reservoir when it is placed on a long lateral of, say, 6,000 or 7,000 feet. A lateral is the horizontal portion of a well.

"How do I actually get to the [areas] that don't produce at all and crack those open?" said Richard Spears, vice president of oil services consultants Spears & Associates. "You can do it, but the challenge and cost of doing it can be big. It's technically risky, economically expensive, and in the end, will you really get something out?"

Refrac Activity


Refrac Count

Bakken Oil and Gas Production

Bakken Initial Stimulation Success

Average Cumulative Oil Production, BBL

Significance: IF due to improved completion technology (design), even 2016 wells will need to be refrac’d......and we may well be refrac’ing previously refrac’d wells.

Production Month

Bakken Cumulative Production

Main Counties
- Mountrail
- McKenzie
- Dunn
- Williams
- Bowman
- Divide
- Burke

Bakken Top Producers

As of August 2017
1. Continental Resources
2. Whiting
3. Hess
4. Oasis
5. ExxonMobil
6. ConocoPhillips
7. EOG
8. Marathon
9. Statoil
10. WPX

Bakken Refracs

Recompletion...
- REFRAC
- NONE


Bakken Refracs

~185 total refracs in the Bakken in ND

"While careful work was performed to discover as many non-confidential, modern refracs as possible, this data set is likely not all inclusive.

J.J. Kringstad, North Dakota Petroleum Council Annual Meeting, September 28, 2017
Bakken Refracs

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BPOP Mtg: Noval Refrac Developments and Challenges
November 2017

Bakken Refracs

Color: Data quintiles

~90% of Bakken refracs are lowest performing wells

www.info.drillinginfo.com, "What makes a Successful Refrac?", Mar 28, 2017

BPOP Mtg: Noval Refrac Developments and Challenges
November 2017

Bakken Refracs

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<td>Ave. Max. Recompletion. bopd</td>
<td>Ave. Max. Original Completion. bopd</td>
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BPOP Mtg: Noval Refrac Developments and Challenges
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**Bakken Refracs**

Distribution of incremental oil only EURs (mbo) for 83 Bakken refracs

- 25%: >250 mbo
- 24%: 200-250 mbo
- 17%: 150-200 mbo
- 12%: 100-150 mbo
- 10%: 50-100 mbo
- 6%: 0-50 mbo
- 6%: 0

C. Nolan, “To frac or refrac? Insights from the Bakken”, Search and Discovery Article #80565 12/19/2016

**Whiting Refrac Project**

Candidate Selection
Two key parameters for Re-frac candidate selection are high pre-Re-frac reservoir pressure (>4000 psi) and the reservoir flow regime of the candidate well. Refrac results from the area indicate that a candidate well in Transient Flow will have a significantly higher probability of success than a candidate well in Boundary Dominated Flow. The Two Shields Butte 14-33-6H candidate well meets both these pre-Re-frac criteria of high reservoir pressure and Transient Flow Regime.

Williston Basin Refracturing Pilot Shows Promise for Older Bakken Wells

Figure 2. Production graph of Two Shields Butte 14-33-6H pre & post refract w/ artificial lift

Two Shields Butte 14-33-6H Refrac Project, June 2017 Report to the North Dakota Oil and Gas Research Council

**Whiting Refrac Project**

Prior to completing the refrac, the TSB 14-33-6H had an EUR (Estimated Ultimate Recovery) of 360 Mbo, the estimated gain from the refrac was 100Mbo or an EUR of 360 Mbo. Actual well performance indicates the initial pre-refrac reserve projections will be met or exceeded. Using the estimated decline curve from the pre-refrac analysis fitted to the actual early time production, the EUR prediction is now 369 Mbo, 5,000 additional bbls over the original projection.

Two Shields Butte 14-33-6H Refrac Project, June 2017 Report to the North Dakota Oil and Gas Research Council
Candidate Selection: The Key to Refracs

Candidate Selection Criteria:
- **Underperforming wells** - wells in which the initial fracture treatments is known to have pumped small volumes, low proppant concentrations, or a damaging fluid type;
- **Early completion designs** (too few stages and/or large spacing) – wells with potentially large sections of the wellbore that were not accessed initially;
- **Significant remaining reserves** in the well’s drainage area;
- **High quality rock** – and knowledge of natural fractures and rock fabric;
- **Known geomechanics and stress**; and
- **Known potential for frac “hits”** on offset wells

Refracs Methods (1)

Refrac Methods Include:
- **“Pump and Pray” (PnP)** – bullhead with diverter-laden fluid (biodiverseters), perhaps with 100 mesh or nano-prop, to access clusters previously unstimulated. Likely the cheapest refrac but likely only modest success.
- **Add New Perfs** – essentially PnP with the addition of new perforations to potentially access additional rock.
- **Near-wellbore Proppant Placement** - restoring proppant at the intersection of the fracture and the wellbore to address overflush issues.

Refracs Methods (2)

Refrac Methods Include:
- **Cementing Off Existing Perforations** - where tracers or production logs have indicated no flow, adding new perforations along the lateral. Done properly, this could be an “engineered refrac”.
- **Running a Liner to Seal Off Old Perforations** – essentially similar to cementing of old perforations.
- **Staddle Packer Isolation** - refracturing specific intervals with a straddle packer on tubing or coiled, in combination with new or old perforations. Likely the most costly method but potentially the method with the greatest uplift – particularly if the rock and geomechanics are understood.
**Diversion-Only Refracs**

A primary focus of current refracs is DIVERSION.

- Diversion is often successful because of the challenges with limited-entry, cluster stimulations. These challenges with limited-entry designs have been known for 30+ years!
- The primary success of Diversion Refracs proves the primary failure of the original stimulations design (i.e., limited-entry design).
- Given this, why is limited-entry still used? More importantly, why are folks going to MORE clusters per stage (hoping limited-entry somehow works better).
- Also, consider Diversion+ Refracs (plus 100 mesh or more proppant/ft, etc)
"Engineered" Refracs

Another potential success of refracs is that we simply do not see the drainage area from a given cluster that was hoped for (as based upon cluster spacing). In part, this arises due to a fundamental lack of understanding, data, and diagnostics on drainage area (and the, often – very - misleading information we have obtained from microseismic data).

During the refrac, via additional location-specific perforation and stimulation, we focus the refrac on the best parts of the formation based upon detailed, site-specific Candidate Selection.

But, we have to understand the rock....

Unconventional Play Fabric Scenarios

<table>
<thead>
<tr>
<th>Highly Fractured Rock Mass</th>
<th>Weakly Cemented or Partially Open NFs</th>
<th>Non – or Strongly Cemented NFs</th>
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<tbody>
<tr>
<td>Fault Zones</td>
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<tr>
<td></td>
<td>• Limited or no HF is created.</td>
<td>• Treat as conventional HF.</td>
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<td></td>
<td>• Characterize NF sets for differences.</td>
<td>• Economics of multiple stages.</td>
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<td></td>
<td>• Optimize operational parameters.</td>
<td>• Optimization of length/area in pay.</td>
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<td></td>
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<td>• Stress Shadows</td>
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<td>• Casing deformation.</td>
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HF=Hydraulic Fracture
NF=Natural Fractures/weakness planes

What is our design objective:
• Create a high conductivity main HF; or
• Optimize access to rock fabric
Influence of Rock Fabric

Sparse DFN  Dense DFN

Plan view (at injection pt) of pressure & MS events

HF Aperture & Proppant Transport

Sparse DFN  Dense DFN

X-section view (at injection pt) of HF aperture

On The Geomechanics of Refracs

If a fundamental objective of a refrac is diversion at the wellbore, then geomechanics may be trivial (consider that a poorly diverted cluster is undepleted – the reason it increases production – which means a HF propagating from this cluster should not be significantly impacted by rock fabric or depletion from other clusters)
On The Geomechanics of Refracs

- Now, if that undepleted cluster sits just next to a depleted cluster, that depletion causes a change in stress (often a reduction, but...). The primary question here is whether the depletion has caused a ROTATION in the stress field; if there has not been a rotation, then the zone may treat at a lower pressure, but the geomechanics are still largely trivial.

- Where the geomechanics becomes a significant issue is the refrac of pre-stimulated clusters (i.e., those with depletion). Here, the flow of frac fluid and proppant will be governed by the depletion-induced stress field as well as the high-conductivity pathway generated by the original stimulation. Furthermore, the issue of leakoff needs to be considered.

On The Geomechanics of Refracs

- The geomechanics of depleted formations absolutely depends on knowledge of the location and magnitude of depletion – if these aren’t known, the geomechanics cannot be resolved!
On The Geomechanics of Refracs

The geomechanical simulation of stress changes with depletion, as shown here, is trivial — and has been done for 20+ years. The challenge is understanding where, and at what magnitude, pressure has changed in the rock mass for Unconventionals.

Refrac Timing

- All things being equal, the sooner an under-performing well is refrac’d, the better the economics (within the constraints of operational issues and operational economics).
- IF under-performance is time-dependent (e.g., natural fracture closure with depletion), timing becomes more complicated.
- “Defensive Refracs” are timed based upon the need to protect offset laterals.
- “Opportunity Refracs” are timed to address down-time for frac crews and equipment.

Refracs: Do We Really Get Uplift?

- Are we simply seeing “Flush production”
  - If so, this can be tested (and would be much cheaper...)

- Are we performing a pseudo-EOR operation
  - Is the refrac a waterflood-like sweep between fractures.....

- For a given well – the primary effect of a refrac will depend on most of the issues mentioned here.
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