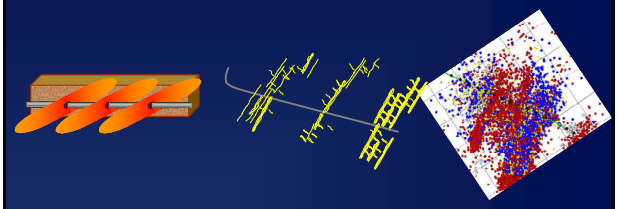
Missed Opportunities: How NOT to Pump a Refrac



Mike Vincent
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Microseismic image: SPE 119636

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Mike Vincent

Consulting Engineer
FracWell

Mike Vincent is a consulting engineer with more than 25 years of experience; specializing in fracture optimization and training. After completing his degree at the Colorado School of Mines, he worked with Amoco, ARCO and CARBO prior to becoming an independent consultant in 1996.

An active member of the Society of Petroleum Engineers, Vincent has authored over 30 technical papers and serves as a technical editor for three SPE journals. Mike frequently lectures at universities and presents fracturing schools to numerous companies and organizations. He has served as an SPE Distinguished Lecturer and Distinguished Author. For more information, contact mike@fracwell.com

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Caveat & Goals

- In one hour, I won't be able to cover everything you would like
- My most popular refrac courses are 2-½ to 3 *days*
  - And we still don't cover every question
- My goals today include:
  - Challenge your notions about restimulation
  - Show field examples
    - List two papers summarizing >140 published refrac studies
  - Help establish the mindset so you can:
    - Incorporate learnings from other studies
    - Select reasonable candidates
    - Learn something from your first refrac attempt
    - Improve initial frac designs, well spacing, refrac approaches…

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Refracs

My definition of refrac

- A second propped fracture treatment (with production data between!)
- Also tri-fracs, quads-, "cinco-de-fraco" … "octo-frac"
- Some operators distinguish between recompletions (adding perfs) and refracs (through same perfs)
  - I use the term "refrac" for both, but carefully track details
- I have excluded a large dataset where propped fracs improve previous acidized or unpropped initial treatments
  - Can learn about durability of unpropped portions of the frac

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Topics

- Common refrac campaign failures
- Some fun quizzes, real field examples
  - Would you fund this refrac?
- Learnings & Recommendations
  - Candidate selection
  - How to design a refrac program such that you can LEARN
    - Identify damage mechanisms
    - Improve initial completions
    - Harvest the resource with fewer wells
    - Avoid or reduce the need to refrac in the future
- Summary: How NOT to pump a refrac

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Common Refrac Campaign Failures

- Failure to identify specific mechanisms before designing refrac
- Poor candidate selection strategies
- Failure to read and honor the learnings of our predecessors
- Failure to continue optimizing
  - Commonly the first refrac attempt is "copied" from a perceived leader
  - After finding an approach that meets our economic hurdles, we commonly go into "implementation mode"
- Failure to design refrac campaigns to learn something profound AND incorporate those learnings into the design of future wells (including frac design, stage spacing, and well spacing)

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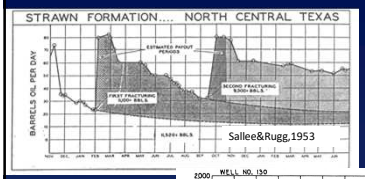
Poll Question

When did the industry begin refracturing wells?

History

1953

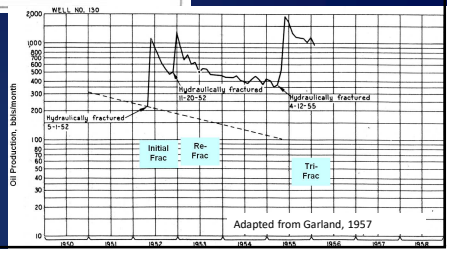


Sallee&Rugg,1953

Observations:
May recover or exceed initial productivity!
Decline rate also reduced!

Does this outcome fit your intuition or model?

1955 – Refrac and Tri-Frac



Adapted from Garland, 1957

Poll Question

How many refracs have been performed?

History

- By 1980
  - 35% of the 1st 500,000 stimulation treatments were refracs
- 1996
  - Only 2-3% of stimulation activity devoted to refracs
- Why?
  - Did we improve design, implementation, durability of initial frac treatments?
  - Did technological evolution cease?
  - Did economic parameters change?
  - Are we no longer staffed to analyze refrac opportunities?
  - Did refracturing fall from vogue and become lost art?
  - Are refracs not as effective as initially believed?
- Current: Desire to *understand* refracturing
  - Of the >6 million frac jobs performed in >2 million wells during the past 7 decades, more than 200,000 have been refracs

It is unacceptable to pump your first refrac without a bit of reading!

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Where Have Refracs Worked?

Well Types

Oil Wells (under primary depletion, waterflood, or EOR)
Condensate Wells
Gas Wells
Gas Storage Wells
Water Production Wells
Water Injection Wells
Steam Injection Wells
Huff-n-Puff , cyclic injection/withdrawal Wells
Disposal Wells

16-page Appendix is attached to SPE 134330 describing field examples

SPE 136757 examined the first 100 Bakken refracs

Formation Types

Carbonates, limestones, dolomites, chalks, evaporites
Sandstones, cherts, siliceous diatomites
Coal (CBM), immature ductile shales, brittle shales
Conglomerates, unconsolidated formations, siltstones

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Where do we have examples of refrac success?

Specific Fields/Formations – Production Wells Only:

- Oil Wells
  - LA Basin, CA
  - Clinton Sand, Ohio
  - Olmos Formation, Texas
  - Undisclosed, 3500 ft S. Texas
  - Norge Marchand Unit, OK
  - Devonian, Crane Cty, TX
  - Westbrook Field, W. TX
  - Pembina Cardium, Alberta
  - Rangely Field, Colorado
  - Kuparuk River Field, Alaska
  - Foothills Cardium, Alberta
  - Colombia
  - China
  - Hassi Messaoud, Algeria
  - Chester, Kansas
  - Vyngayakhinskoe Field, Siberia
  - Kalimantan, Indonesia
  - Bakken & Three Forks MT + ND + SK Vert & HZ
  - Volga/Urals – W. Siberia
  - Arkansas undisclosed XTO field
  - England – Sandstone
  - Waddell Ranch-Mature Carbonate in Permian
  - Midland Farms, Andrews TX (unpublished)
  - Strawn
  - Eagle Ford HZ
  - Niobrara Vert & HZ
  - Viking Vert & HZ
  - Montney HZ
  - Spraberry Vert & HZ
  - Wolfcamp Vert & HZ
  - Cardium
  - Mississippi Lime HZ
- Gas Wells
  - Vicksburg, S. Texas
  - Canyon Sand, Texas
  - Escondido Sandstone, Texas
  - J Sand, Wattenberg, CO
  - Undisclosed 7500 ft depth "low pressured field", TX
  - Oak Hill, Cotton Valley E TX
  - Morrow, Red Fork, Atoka, OK
  - Smackover, Mississippi
  - Mesaverde Group, CO & NM
  - Eastern Gas Shales, MI
  - Mendota, Granite Wash, TX
  - Cotton Valley, LA
  - Almond/Wamsutter, WY
  - Hugoton, KS
  - Green River Frontier, WY
  - Piceance Basin, CO
  - Viking, Ferrier, Alberta
  - Barnett Shale, TX
  - Codell, DJ Basin, CO
  - Medicine Hat, Milk River, Alberta
  - S. Texas undisclosed field
  - Haynesville
  - Eagle Ford Gas Window
- CBM
  - Warrior, Rock Creek, AL
  - Helper Field, UT
  - San Juan Basin, CO & NM
  - Oakwood Field, VA
  - Mannville, AB

The damage mechanisms and ideal refrac designs vary!

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Poll Question

How long should I wait before pumping a refrac?

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When have "Refracs" been Performed?

- Immediately post-frac [not meeting *my* definition of a refrac]
  - Following unsuccessful implementation
  - To achieve new entry points, diversion, reorientation
    - aka Kiel frac, hesitation frac, "relax a frac"…
- Somewhat later
  - Most common published examples are 1-10 years later
- Much later
  - >20 years, Clinton Sand, high perm oil, Ohio
  - >30 years, Mesaverde tight gas sand, Colorado
  - >30 years, Rangely Field, high perm oil, water + CO_2 flood, Colorado
  - >40 years, Pembina mature waterflood, Alberta
  - >30 years, Medicine Hat, Milk River shallow gas
- Ideas available on the theoretically "optimal" time to refrac, but we need to discuss mechanisms first!

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Refrac after 25 years of Depletion?

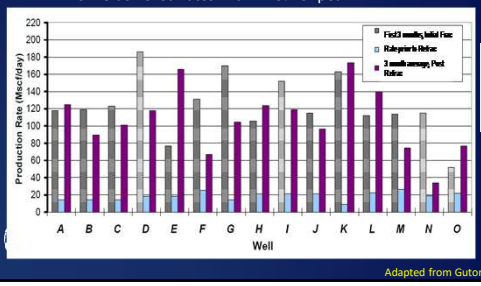
15 refracs (shallow gas – Medicine Hat & Milk River)

All 15 responded to restimulation

Average increase 600-900%

6 of 15 achieved higher production than peak 25+ years prior

4 of 15 achieved rates within 25% of peak IP



Observation: 100% refrac success despite decades of production.

Adapted from Gutor, 2003

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Poll Question

What do operators anticipate to be the most important mechanism when restimulating horizontal wells?

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Most Common (Current) Refrac Target

- Horizontal wells with low stage count
- Why?

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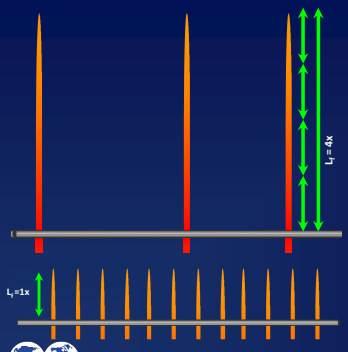
Misleading Models and Intuition



Most operators assumed highly conductive, durable fracs

With that assumption, initial production rates would be solely due to surface area or reservoir contact.

And long-term EUR would be superior with the upper example, with a greater "stimulated volume" contacted by longer fracs.

So… most of the industry used very few frac stages on initial completions and largely refused to invest in higher conductivity.

However, the industry assumptions were wrong!

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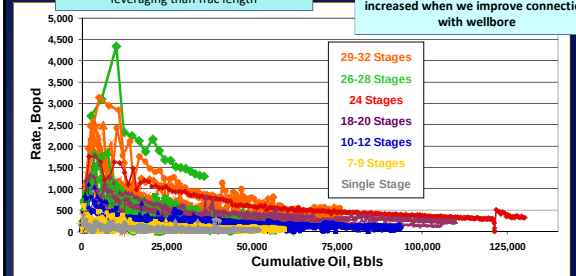
Does it help to break a large treatment into more stages? [Same total mass per Bakken horizontal well]

This was a highly revealing study about frac optimization goals. Number of connection points (frac conductivity) clearly more leveraging than frac length

We see this result in most resource plays. We touch the same amount of rock, but productivity is greatly increased when we improve connection with wellbore



Source: Brigham SPE 134595 and Vincent frac school

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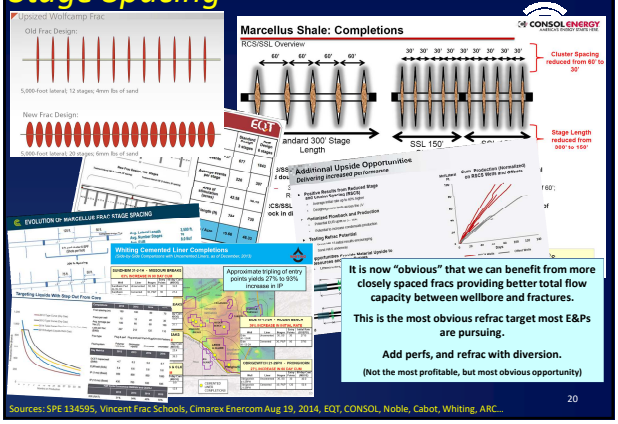
Stage Spacing



It is now "obvious" that we can benefit from more closely spaced fracs providing better total flow capacity between wellbore and fractures.

This is the most obvious refrac target most E&Ps are pursuing.

Add perfs, and refrac with diversion.

(Not the most profitable, but most obvious opportunity)

Sources: SPE 134595, Vincent Frac Schools, Cimarex Enercom Aug 19, 2014, EQT, CONSOL, Noble, Cabot, Whiting, ARC...

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Common Refrac Strategy in HZ wells

Typical Diversion Procedure

- Add perfs
- Pump very large refrac treatments
- Attempt to divert into new entry points (diverter/prop slugs)
- *Obvious candidates, more predictable outcome… but this is an expensive mechanism to address*

Technology Helpful for Optimization

- Appropriate diverters (permanent and soluble)
- Detectable proppant (near- and far-field)
- Microseismic mapping
- Frac hits / well communication evaluation
- Production logging / flow measurement / chemical tracers

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So, diversion is the most common refrac approach by today's E&P operators targeting horizontal wells.

What happens if we fail to divert?

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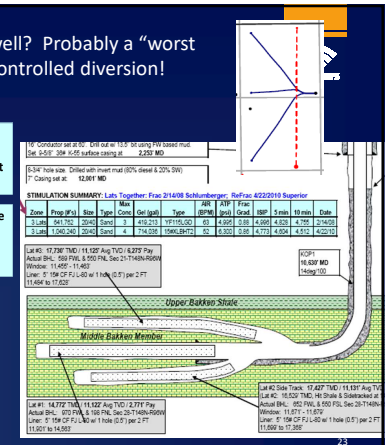
Would you refrac this well? Probably a "worst case" example for controlled diversion!

Tri-lateral
Originally stimulated with 642,000 lb 20/40 sand (44 lb/ft in about 15,000 ft of laterals…)

The least expensive way to restimulate would be a bullhead refrac (no compartmentalization, and no chemical diversion)



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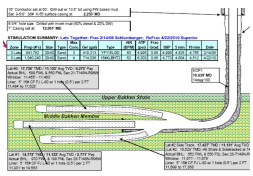
Source: McCrady, Tight Reservoir Completions ATW, Banff 2011

Poll Question

Could we payout a $500,000 refrac on a well like this? [bullhead 1 million pounds of sand, no isolation, no diversion, no cleanout]



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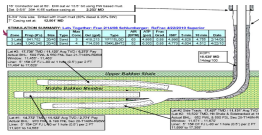
Poll Question

Should we cleanout the multilateral before refrac? A pre-refrac cleanout will cost as much as the refrac. Would you also fund a $500,000 CTU cleanout, effectively doubling the refrac cost?



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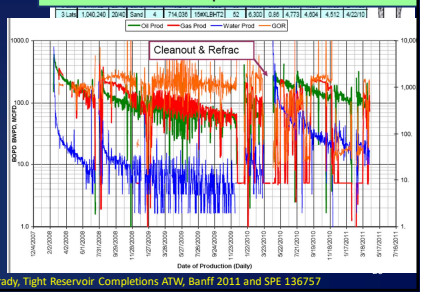
Outcome?

68,000 lbs of sand cleaned out of this well before refrac (11%).

>380,000 lbs of sand (>50% of pumped volume) recovered from some similar "good" wells! [enough to fill 36,000 ft of 5 inch liner, or 20,000 ft of 6" drilled hole]

Pre-refrac cleanouts were important to success of these refracs

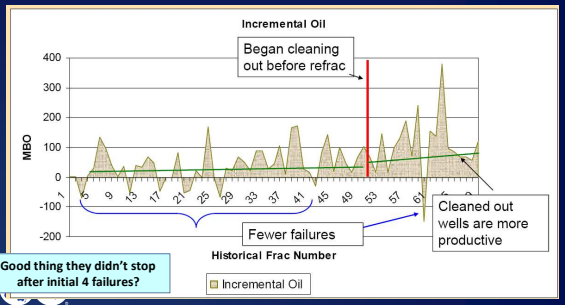
Oil rate increased from 60 to 250 bopd following cleanout and 1,000,000 lb bullhead refrac



Source: McCrady, Tight Reservoir Completions ATW, Banff 2011 and SPE 136757

Were refracs and cleanouts justified?

Headington/XTO/XOM implemented >70 refracs with this strategy between 2006 and 2011.



Good thing they didn't stop after initial 4 failures?

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Source: McCrady, Tight Reservoir Completions ATW, Banff 2011

Why Do Refracs Work? (mechanism)

Why Refracture

The simple reason to refracture a well is to boost production. But to do that, operators need to pinpoint the problems they seek to remedy and then design the proper refracture treatment.

- Address proppant embedment or rock creep.
- Implement new completion learnings.
- Contact virgin rock by adding perforations, diversion, or reorientation.
- Reorient existing fractures to new areas of the reservoir.
- Replace crushed or low-conductivity proppant.
- Bypass damage caused by salt deposition, scale, or fines plugging.
- Fix stages where proppant was overflushed or flowed back into the wellbore.
- Improve the durability of initial proppant.
- Repressurize an existing well before offset drilling and completions.
- Re-energize natural fractures or rearrange existing proppant pack.
- Deliver production chemicals such as emulsion breakers and scale inhibitors.

It appears the combination of leveraging mechanisms is different in each reservoir.

One CEO who attended my class:

"I will fire any engineer in my company who, after attending this 3-day course, designs a refrac without specifying exactly which damage mechanisms they are trying to repair." He continued: "it is *engineering malpractice* to refrac without trying to learn what was done incorrectly the first time."

JPT April 2015 – Trent Jacobs Interview

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Why Do Refracs Work? (mechanism)

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The simple reason to refracture a well is to boost production. But to do that, operators need to pinpoint the problems they seek to remedy and then design the proper refracture treatment.

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Creation of new entry points is an obvious refrac opportunity. Of course we will pursue it. Easy to identify candidates, relatively predictable outcome.

If an E&P solely focuses on the "diversion" mechanism, they often overlook many other refrac opportunities!

Some can be addressed for much lower cost

JPT April 2015 – Trent Jacobs Interview

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Important Comments So Far…

Lots of History

- It is a shame to pump a refrac without benefitting from learnings from the past 200,000 refrac jobs

Intuition (and modeling)

- We will continue to see some surprising and curious refrac results.
- We need to re-evaluate our notions about restimulation before finalizing our refrac program

Mechanisms

- It seems logical that the reason to refrac the Montney might be different than the reasons to refrac the Bakken, Barnett, Haynesville, or Wolfcamp…
- We might want to resist the urge for a single "refrac recipe" to apply in all fields
- If we can identify WHY we need to refrac, we should be able to customize the treatment to be more effective and less costly

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Why Do Refracs Work? (mechanisms)

Refrac success (worldwide) has been attributed to:

- Enlarged frac (more reservoir contact)
  - Improved pay coverage (add pay in vertical wells)
  - Better lateral coverage (horizontal wells)
- Increased frac conductivity
  - Restore conductivity lost – frac degradation
  - Address unpropped/poorly propped portions
- Improve wellbore-to-frac connection/conductivity
- Reorientation
- Use of more suitable frac fluids
- Re-energizing natural fissures
- Other mechanisms

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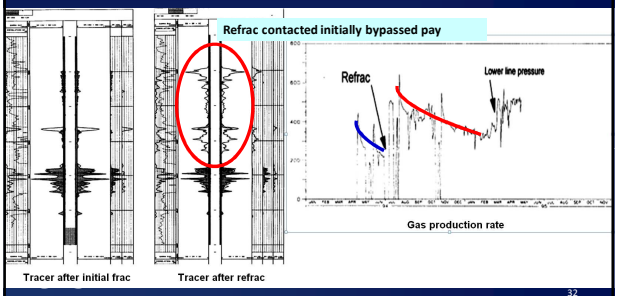
Improved Reservoir Contact

- Bypassed Pay in Vertical Wells
  - Where radioactive tracers or detectable proppants indicated missed opportunities, refracs are frequently successful



Hugoton - Adapted from Hecker, 1995

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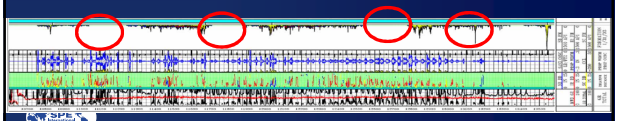
If you pumped a refrac into this well, where would the proppant tracer go?

Cemented single lateral, Middle Bakken, intentionally drilled for longitudinal growth

Several "gaps" in lateral coverage following 300,000 lb 20/40 RCS

If you hydroblasted new slots, could you push proppant into the new perforations with a bullhead refrac?

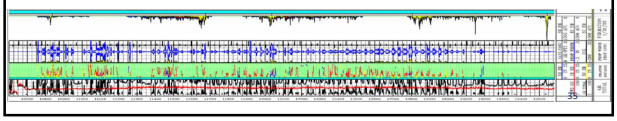
Sand slugs and perf balls used



Source: Lantz, 108117, showing ~3000 ft of lateral

Poll Question

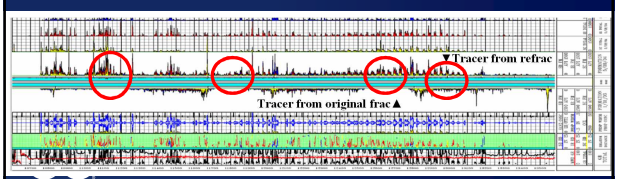
If you bullheaded a refrac into this well, where will we observe the majority of new proppant tracer?



Where did the proppant tracer go?

Tracer signal stronger in new entry points than in original (similar to refracs in short laterals in the Marcellus, Barnett and numerous other fields)

Following this refrac, what production would you expect?



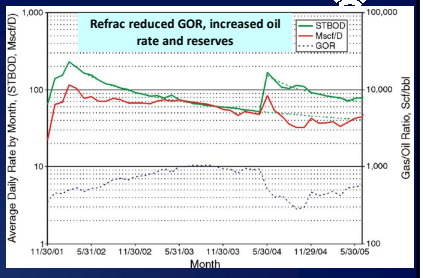
Source: Lantz, 108117

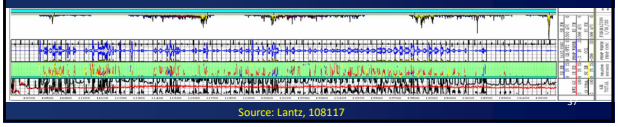
What production would you expect?

Oil rate up, GOR down, diverted into undrained portions of reservoir.

16 successes, 1 well with mechanical problem.

EUR increased by 1.3 mmbo in 16 refracs





Source: Lantz, 108117

Diversion in Horizontal Wells

- So…
  - In short laterals, I have many examples of impressive coverage of the lateral, even without aggressive diversion efforts
  - And even in longer laterals, if the "refrac" is performed relatively soon before significant pore pressure depletion, I have examples of excellent diversion via stress shadowing without any additives…
- But are we getting good diversion in *long* laterals after significant depletion?

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Diversion in HZ Wells

SPE-174979 2015: Dataset contains >65 wells that were restimulated the past ten years.
Challenging to consistently stimulate laterals beyond 2300 ft.

Similar plots shared for Barnett, Eagle Ford, Haynesville, Marcellus, Woodford, Niobrara.

Bullhead refracs as commonly implemented have failed to achieve sufficient stimulation of long laterals

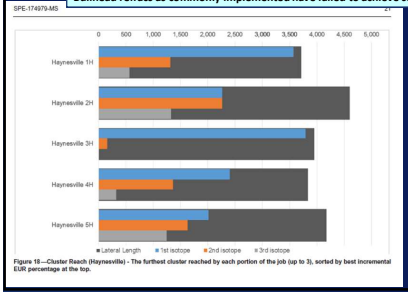

Figure 18—Cluster Reach (Haynesville) - The furthest cluster reached by each portion of the job (up to 3), sorted by best incremental EUR percentage at the top.

There are many approaches to improve proppant distribution in these long laterals that we would discuss in a longer seminar

SPE 174979 ProTechnics

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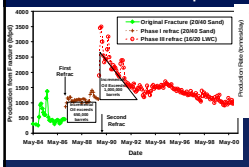
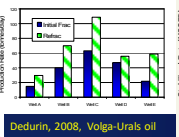
Increase Conductivity in Refracs?

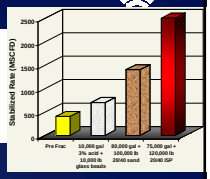
Dozens of examples in literature



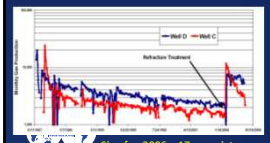
Pospisil, 1992 – 6 years later, 20 mD oil



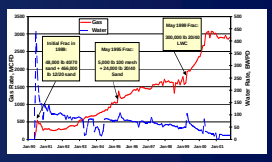
Dedurin, 2008, Volga-Urals oil



Ennis, 1989 – sequential refracs, tight gas



Shaefer, 2006 – 17 years later, tight gas



Vincent, 2002 – 9 years later, CBM

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Why Do Refracs Work? (mechanisms)

Refrac success (worldwide) has been attributed to:

- Enlarged frac (more reservoir contact)
  - Improved pay coverage (add pay in vertical wells)
  - Better lateral coverage (horizontal wells)
- Increased frac conductivity
  - Restore conductivity lost – frac degradation
  - Address unpropped/poorly propped portions
- Improve wellbore-to-frac connection/conductivity
- Reorientation
- Use of more suitable frac fluids
- Re-energizing natural fissures
- Other mechanisms

In longer webinars, we would cover examples of these refrac mechanisms.

We must skip them today for time

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A More Enlightening Refrac Mindset

- Suppose you wish to identify whether the beneficial refrac mechanism is far-field or near-wellbore
- What could you try?
- Pump a tiny refrac?

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Poll Question

Can we distinguish far-field and near-wellbore issues by pumping a tiny refrac?

Existing wells, single Bakken laterals

Initially fraced in mechanically isolated stages

Initially used > 2 million pounds of sand [1000 T] in crosslinked fluid

What would happen if I bullhead in less than 5% the mass of ceramic proppant 100,000 lbs [<50 T]?

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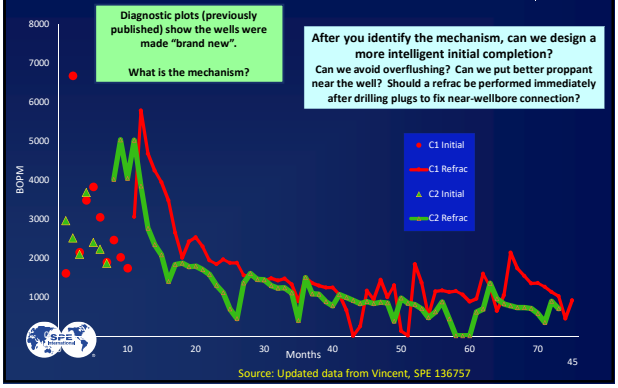
Results after restimulating with small volume of ceramic proppant

Diagnostic plots (previously published) show the wells were made "brand new".

What is the mechanism?

After you identify the mechanism, can we design a more intelligent initial completion?
Can we avoid overflushing? Can we put better proppant near the well? Should a refrac be performed immediately after drilling plugs to fix near-wellbore connection?



Source: Updated data from Vincent, SPE 136757

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A More Enlightening Refrac Mindset

- In oil reservoirs, use the GOR as a built-in tracer!
- Take your best guess at the mechanisms that explain the GOR trend and use that to predict outcome after restimulation
- Use the learnings to challenge your mechanism

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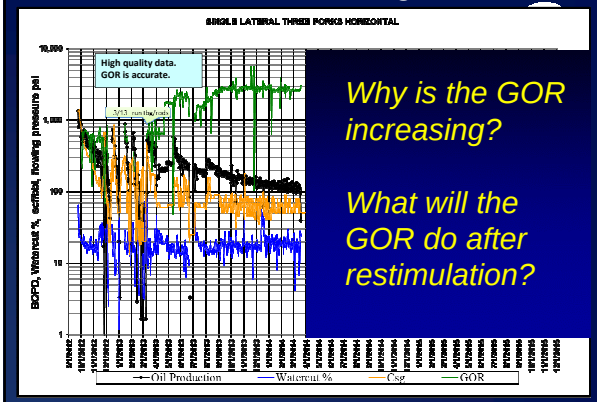
Examine the Climbing GOR

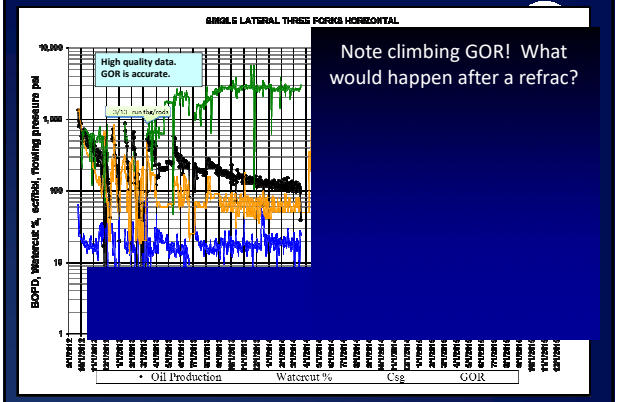


Why is the GOR increasing?

What will the GOR do after restimulation?

Source: Not previously published

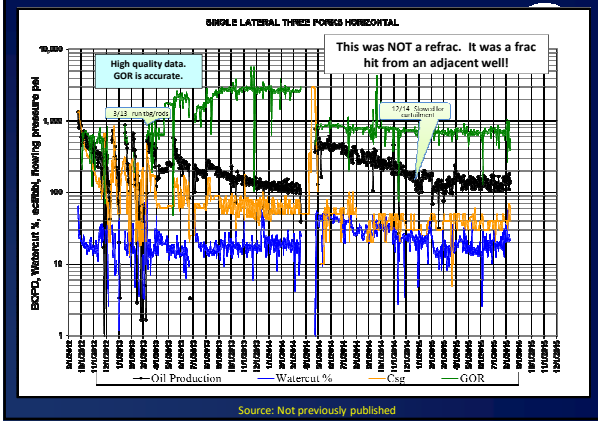
Poll Question



Note climbing GOR! What would happen after a refrac?

Source: Not previously published

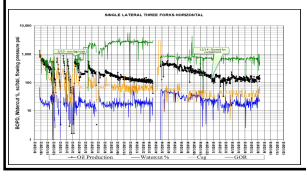
Why is the GOR low and stable after a "restimulation"?



Source: Not previously published

Poll Question

If a frac hit can increase production AND result in a lower and more sustained GOR, which statement would you agree with?



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Additional Impressions…

Refracs appear to work by a variety of mechanisms.

We don't evaluate ALL the mechanisms. Most operators fail to anticipate and investigate many inexpensive opportunities.

We fail to find the most cost-effective refrac approach.

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Diagnostic Value! Opportunity to resolve "non-unique" Interpretations

Is the decline suggesting:

- **Poor reservoir quality?**
- **Limited drainage area?**
- **Insufficient frac length?**
- **Degrading frac conductivity?**

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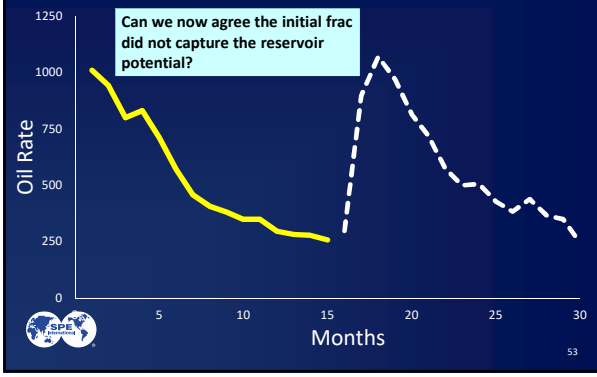
Diagnostic Value! Opportunity to resolve "non-unique" Interpretations



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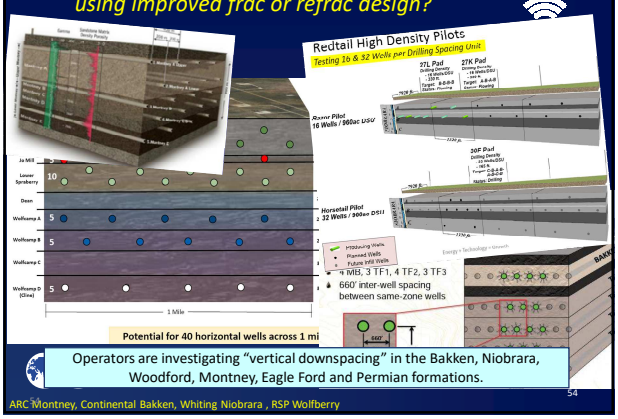
Can we harvest the reserves with fewer wellbores using improved frac or refrac design?



Operators are investigating "vertical downspacing" in the Bakken, Niobrara, Woodford, Montney, Eagle Ford and Permian formations.

ARC Montney, Continental Bakken, Whiting Niobrara , RSP Wolfberry

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How NOT to Refrac (1 of 2)

- Do NOT refrac without carefully identifying which mechanisms you are attempting to address
  - Clarify alternative designs, plus document failure/success for future engineers
- Do NOT forget to read a few case studies
  - SPE 134330 has a great bibliography
- Do NOT merely try to rehabilitate underperforming wells
- Do NOT merely copy a refrac design from a perceived leader
  - Where do you think they got their design?
- Do NOT quit after one failure
  - Unless candidate #1 was very carefully thought through!
- Do NOT forget to gather cheap data
  - Salinity, GOR, gel residue, timing & magnitude of frac hits
  - And *strategically* collect even expensive data?
- Do NOT optimize well spacing before optimizing frac and refrac strategy. (Ideally in conjunction/iterative)
  - Can restimulation alter your well spacing?
  - Don't pride yourself in "Drilling Inventory" more than NPV

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How NOT to Refrac (2 of 2)

- If you have a large portfolio of wells, do NOT only refrac unusual wells
  - Instead find a way to profitably refrac "typical" wells, and replicate/enhance success across large well population
- Do NOT fail to design a refrac pilot to learn something
  - Instead, learn something that can improve your next refrac
  - Lean something that can improve your next new well
- Do NOT fail to harvest "low hanging fruit"
  - Can you cheaply address salt deposition or overflushed stages?
- Do NOT merely *repeat* a successful refrac design
  - We are NOT yet optimized. Keep improving!
- Do NOT forget to learn something, and to apply those learnings to your future developments
  - The biggest win will be to learn something that can reduce the required number of wells, number of stages, or eliminate the need to refrac future wells.

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