27th WORLD GAS CONFERENCE WASHINGTON DC | JUNE 25-29 2018
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Variable Rate Fracturing – A Step Change in Hydraulic Fracturing

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#WGC2018
FUELING THE FUTURE

Problem: Low perf efficiency hinders well performance

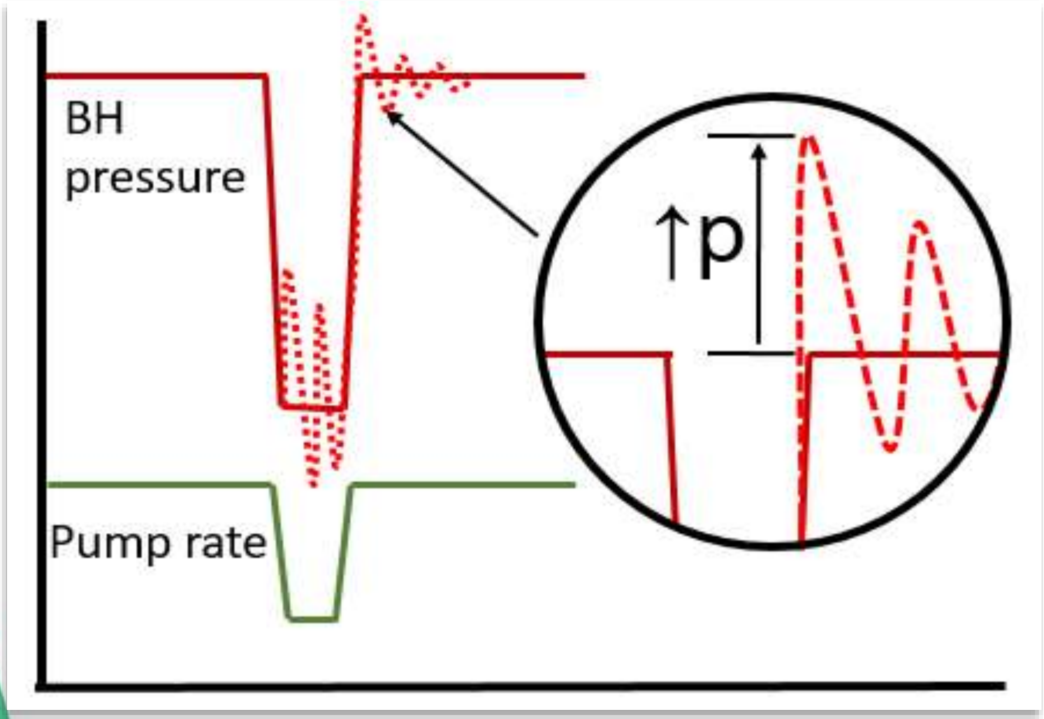
1. Perforation breakdown efficiency is low, **<60%**
   - Centralization: Cement thickness
   - Variations in rock composition
   - Variations in stresses

Variations in perforation breakdown pressures can exceed 1000's psi*

2. Few tools effectively address it
   - Ball sealing: low controllability, increased time, challenging in horizontals
   - Engineered perforations: concentrating on good pay doesn't address perforation breakdown
   - Specialized perf guns: perf pattern and gun placement don't guarantee perf opening

*Perforation breakdown pressures at various horizontal stress anisotropies and pore pressures.
Waters, George, "Fracture Initial Pressures and Near-Well Hydraulic Fracture Geometries in Cemented, Perforated, Horizontal Wells, Hydraulic Fracturing Journal, July 2017, Vol:4#3

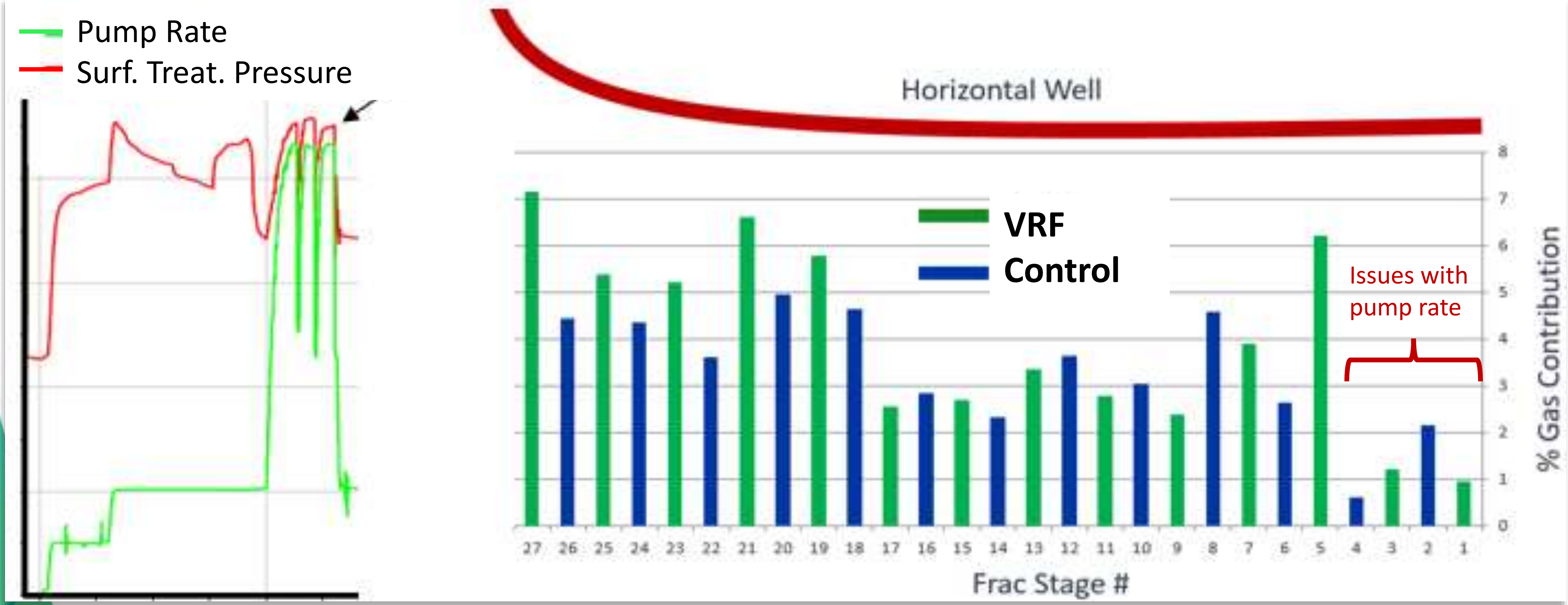
Breakthrough – Patented* Variable Rate Fracturing (VRF) Technology
A step change (literally) for improved perforation efficiency



(*) US Patents 9,581,004 & 9,879,514, 9,982,523 + others pending

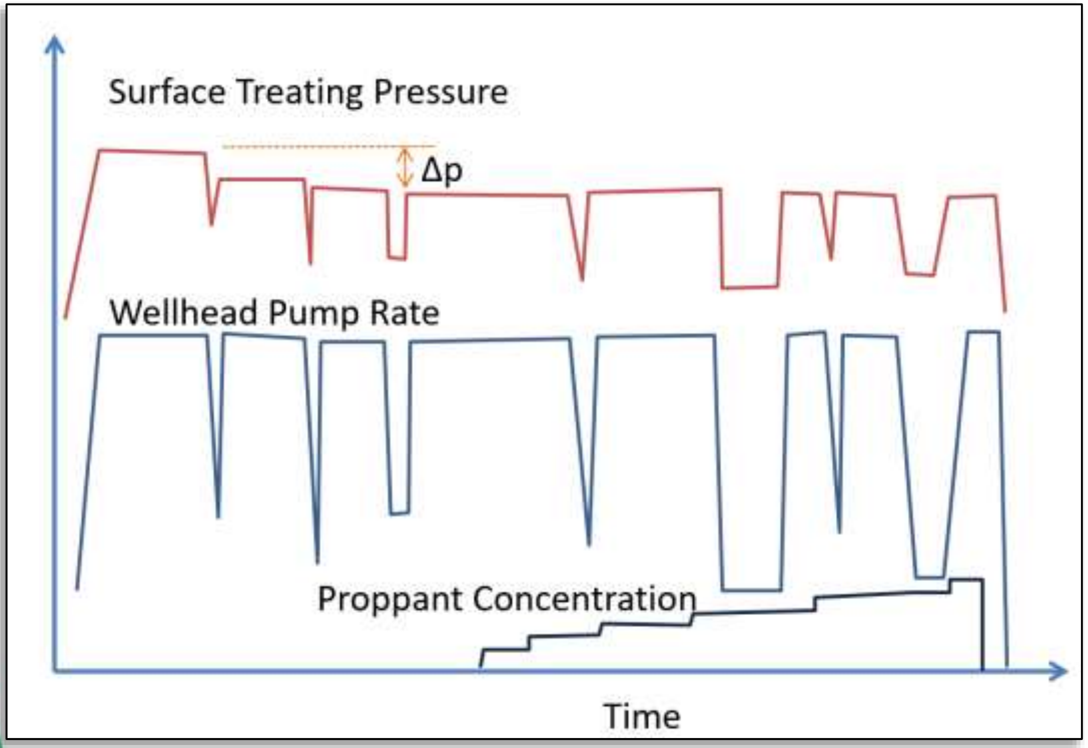
- VRF uses engineered rate changes throughout fracturing treatment to:
  - Induce pressure pulses which travel up and down the wellbore
  - Pressure pulses combined with original limited entry fracturing pressure can be much higher, thus exceeding breakdown pressure of non-open perforations
- Enhances both perforation opening and fracture complexity (branching)

Marcellus field test – VRF in odd frac stages



- Very rapid engineered change of pump rate in pad
- No additional equipment or materials needed
- **19% higher average production**

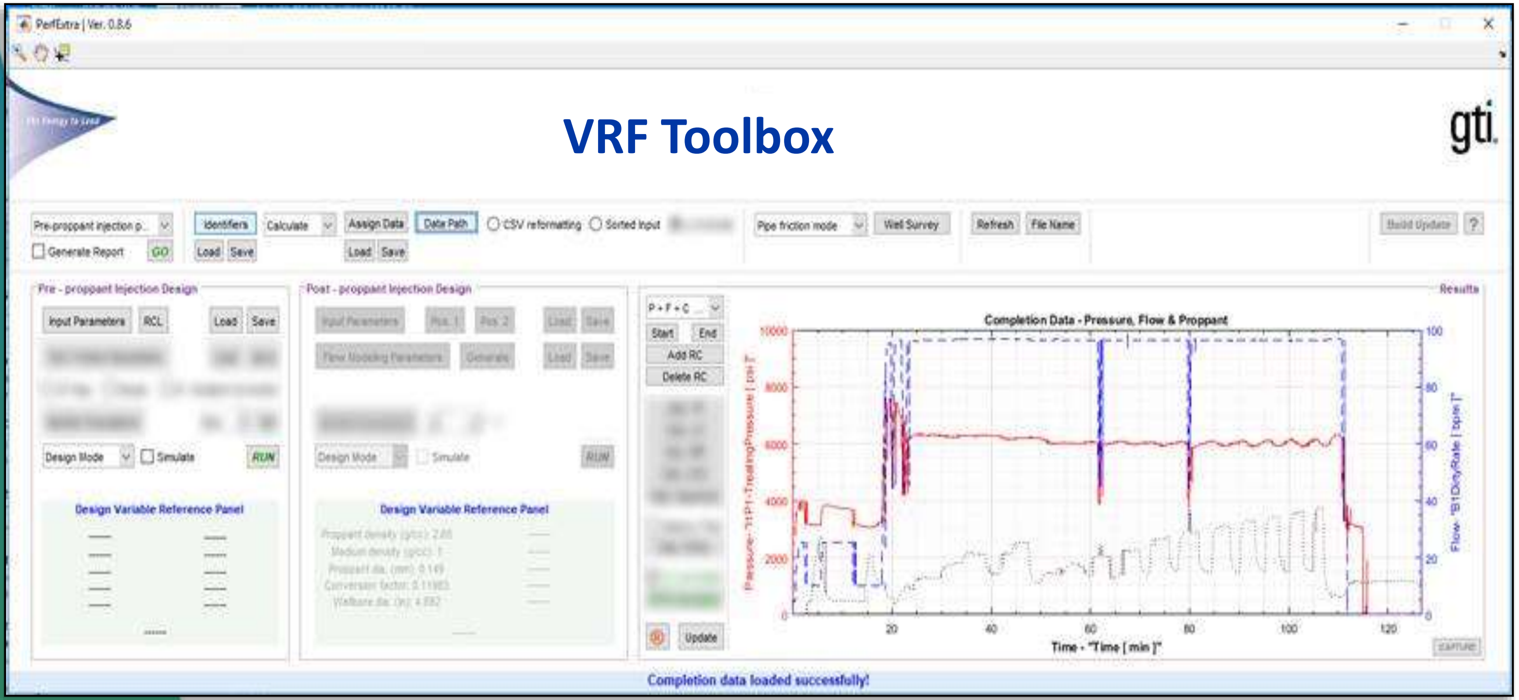
Permian field test – VRF on complete well in Wolfcamp



Production comparison after 14 months

Well	Prod. Increase	Proppant Loading (klbs/ft)
Offset 1	11%	1.8
VRF Well	-	1.1
Offset 2	26%	1.1
Offset 3	23%	1.1
Offset 4	14%	1.1

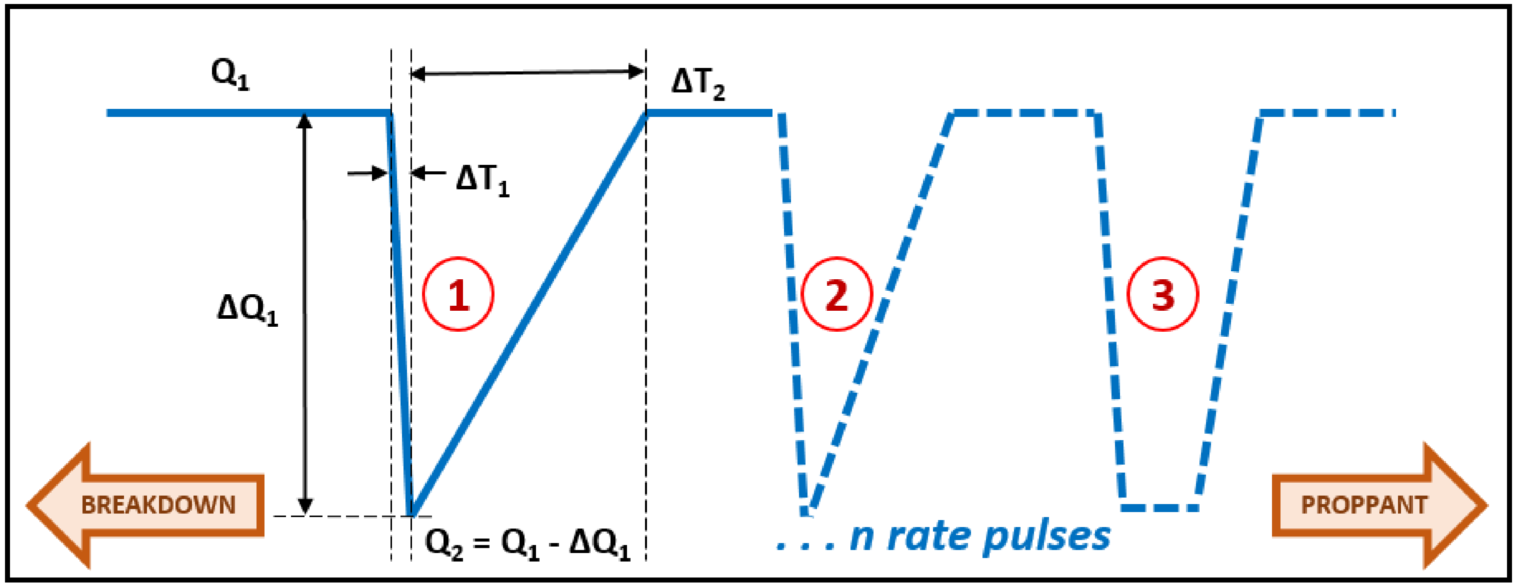
Workflow and toolbox enables design and optimization of VRF treatments– Example of workflow

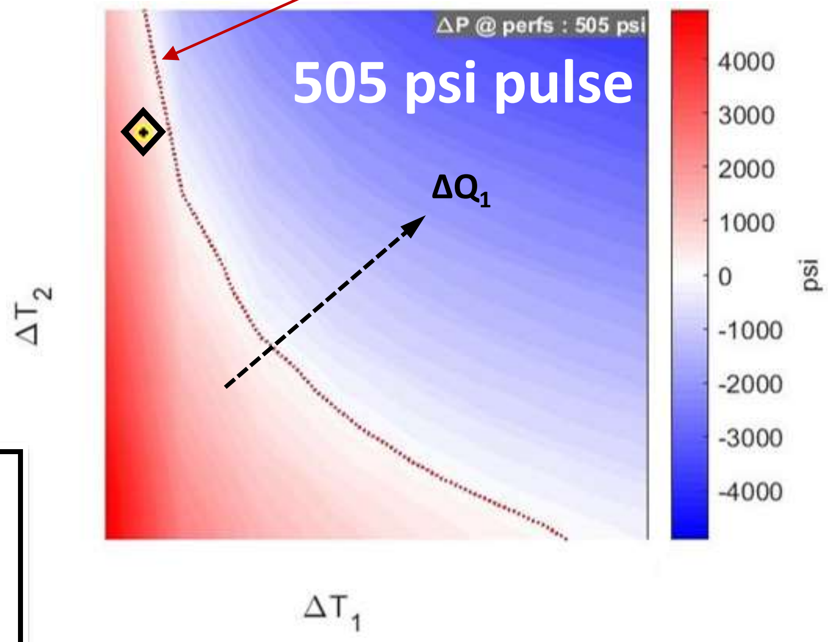


- Using control data design VRF and predict improvement
- Monitor in real time and optimize
- Establish created fracture volume and verify actual production performance with predicted

Design VRF treatment

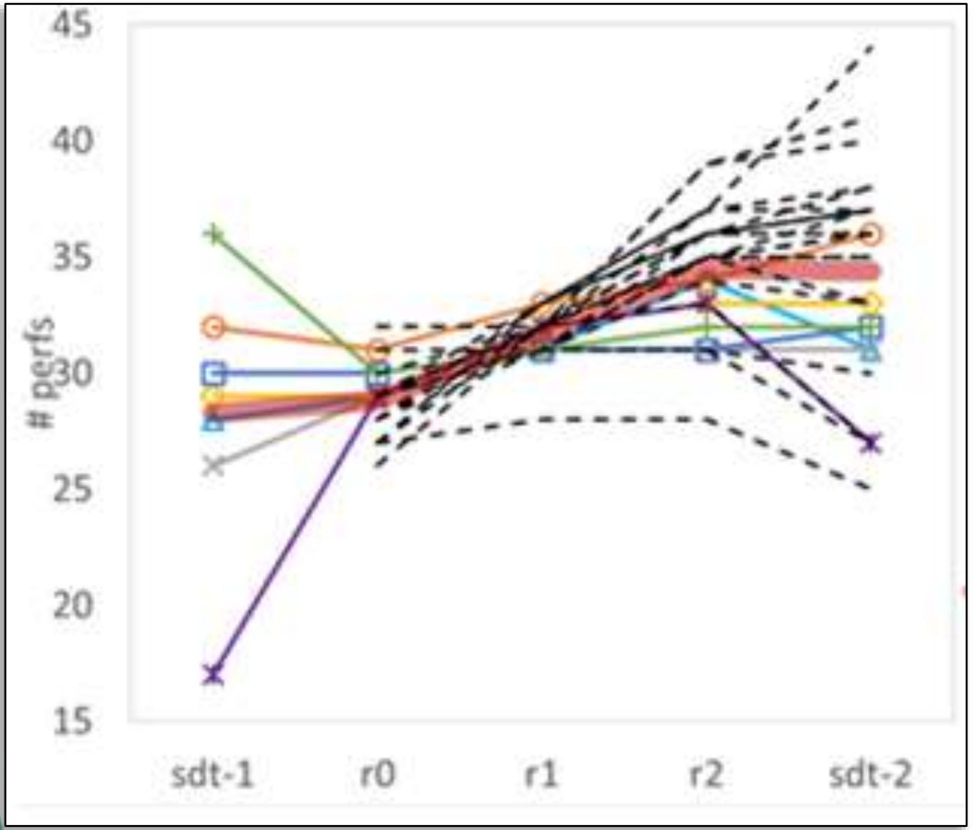
- For a desired pressure pulse magnitude determine magnitude and time interval for the initial rate drop **ΔQ1 & ΔT1**
- & Determine the duration of the rate pulse **ΔT2**.

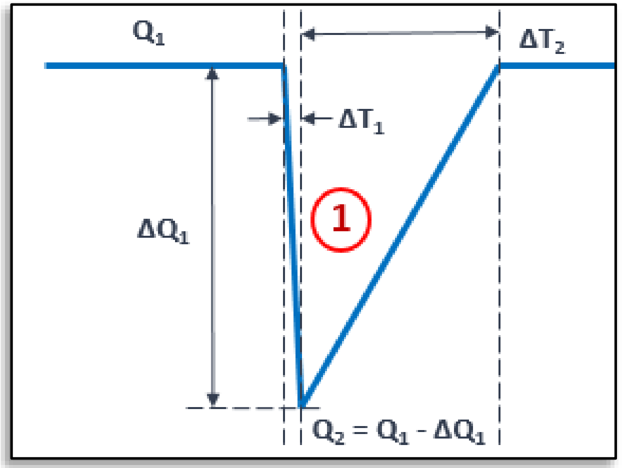




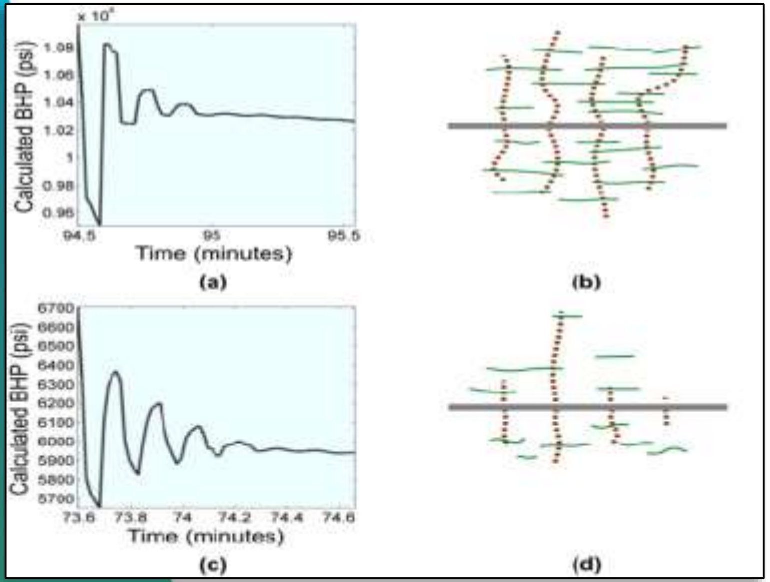
Optimize in real time

- Novel perforation efficiency analysis using classical and proprietary techniques enables:
  - Determination of initially open perforations (baseline stepdown)
  - Effectiveness of each engineered rate pulse
  - Progression of # of open-perforations during treatment (bound solution, lower uncertainty)
  - Optimization of subsequent rate pulses





Calculate fracture volume and production



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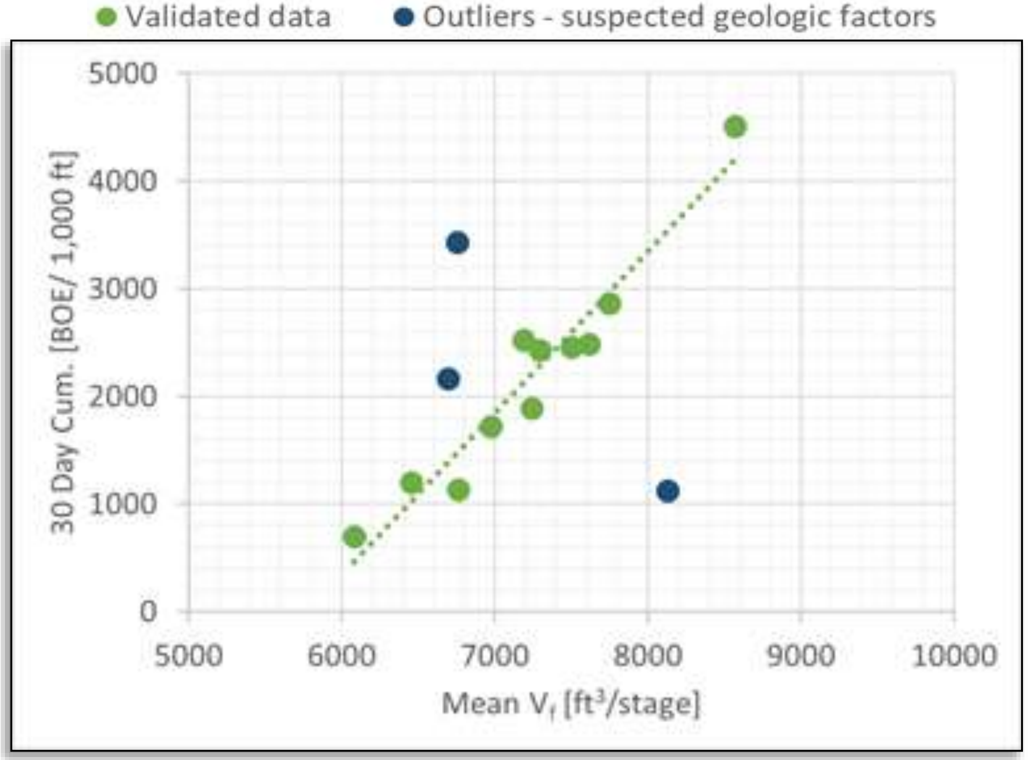
- Using pressure transient data we calculate fracture volume

- Compare fracture volume with production



Summary

- Low perforation efficiency is the main cause for poor horizontal shale well performance
- VRF significantly increases perforation efficiency
- Improved perforation efficiency leads to improved stimulation efficiency by creating more fractures
- Field tests have shown consistent improvement in opening of additional perforations in many wells and shale formations
- Significant uplift in average well production, as high as 30% noted
- Proprietary workflow and toolbox enables design and optimization of VRF treatments

For More Information, Contact:

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