The Evolution of Diversion, An Engineered Approach

James Rodgerson

Completions Advisor

Westside SPE Luncheon
February 20, 2019

Overview

- Introduction
- Evolution of Diversion Technology
- Perforation Efficiency
- POD Diversion Systems
- Deployment Methods
- Case Studies
- Summary

Overview

- Introduction
- Evolution of Diversion Technology
- Perforation Efficiency
- POD Diversion Syste
- Deploymen
- Case Studi
- Summary

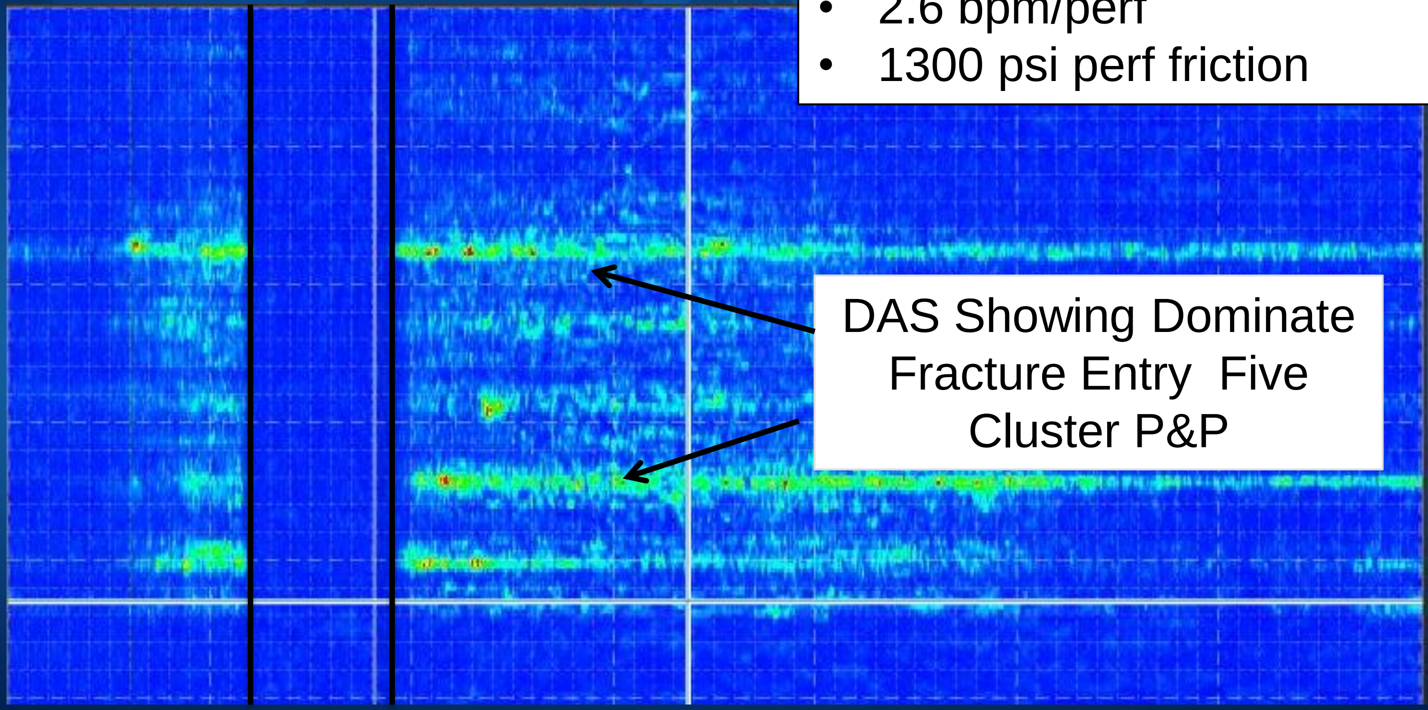
Why Diversion

A case for Diversion

- New Well
  - Increase cluster efficiency via intra-stage diversion
  - Lengthen lateral coverage - stage size
  - Replace or reduce the number of Frac Plugs
- Remedy for casing problems
  - Temporarily seal leaks
  - Casing restrictions to frac plugs and BHAs
- Offset well interaction
  - Reduce the risk of frac hits
  - Increase production of offset wells
- Re-Fracs
  - Seal existing perforations and/or sliding sleeve ports
  - Promote propagation into new perforations through stage sequence diversion

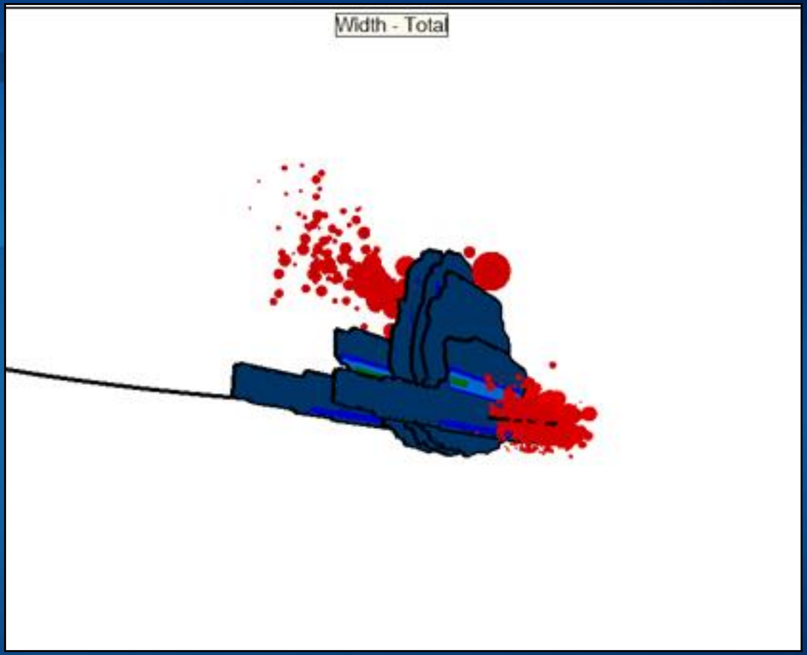
Increase New Well Fracture and Cluster Efficiency

- 5 Clusters .40 shots 6 spf
- 30 Perforations
- 80 bpm
- 2.6 bpm/perf
- 1300 psi perf friction



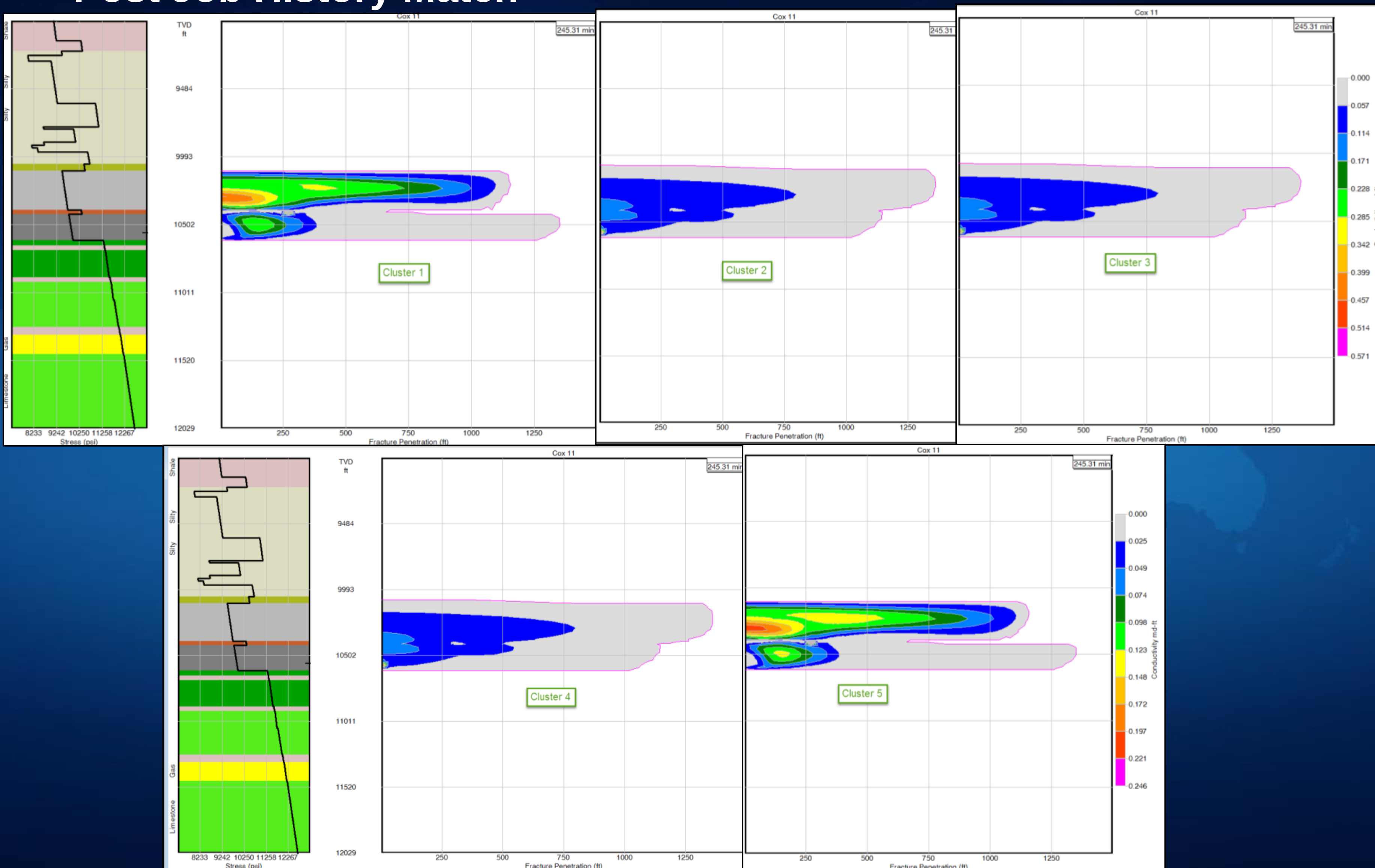
Fiber optic DAS Perforation Cluster Efficiency

Microseismic vs HF Model



Fracture Efficiency 30% effective at best

Post Job History Match



How can we Improve Cluster Efficiency

- Geo-Engineered Design (perforate like rock)
- Limited Entry
- Extreme Limited Entry
- Perforation Design
- Intra-Stage Diversion
- Plug Elimination

Considerations to Improve Cluster Efficiency

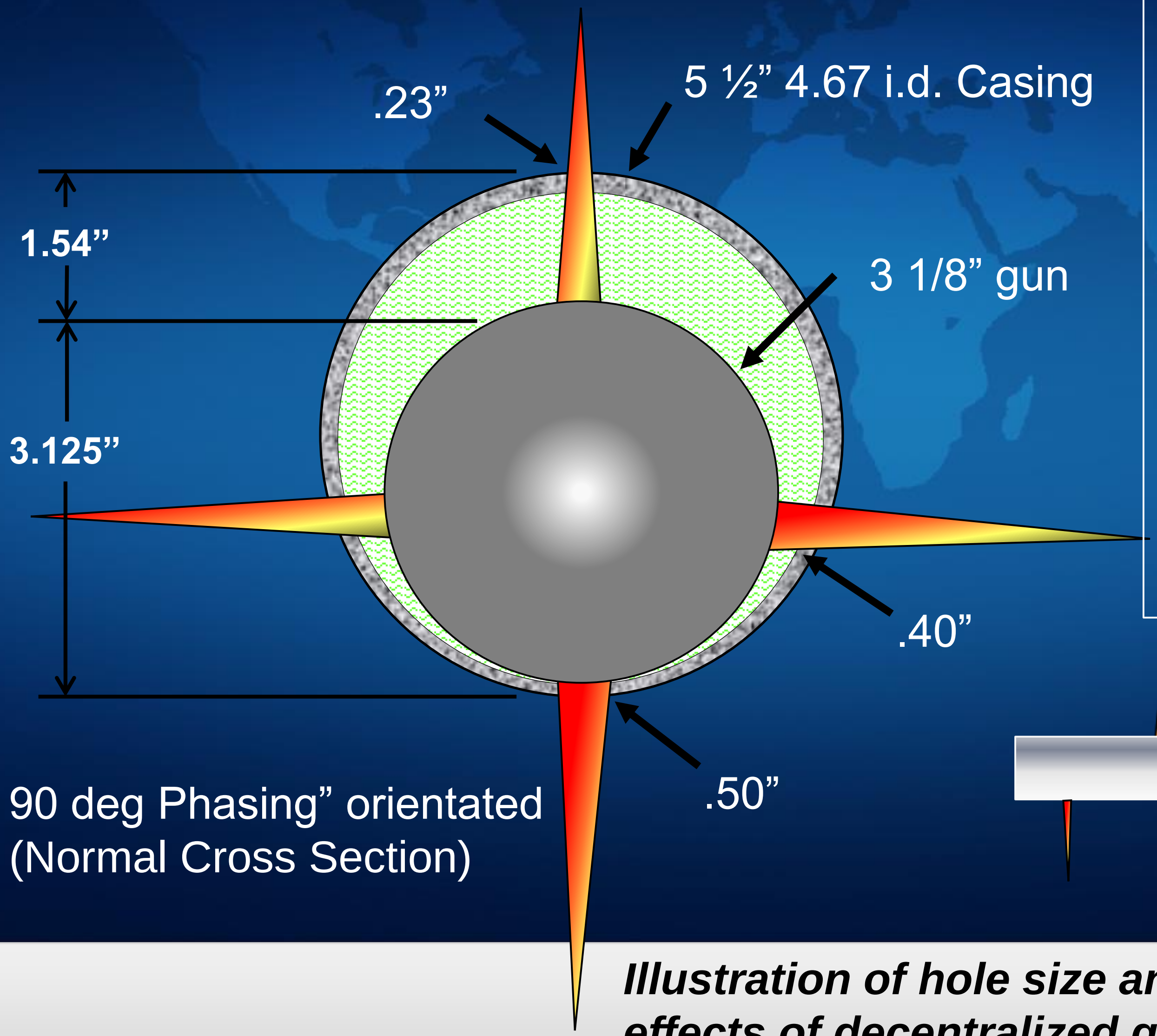
- Limited Entry
  - Better Fracture initiation
  - Should consider consistent hole sizing
  - Perforation Erosion can be an i
- Diversion C
  - Perfora
  - Fracture
  - Diverter type
  - Intra-Stage Diversion
- Geo-Engineered Completions
  - Cluster placed in “Like Rock”
  - Understand in-situ stress and NWBFP
  - Stress Shadowing

Perforation Strategy

Considerations to Improve Cluster Efficiency

- Limited Entry
  - Better Fracture initiation
  - Should consider consistent hole sizing
  - Perforation Erosion can be an issue
- Diversion Considerations
  - Perforation design strategy
  - Fracture design
  - Diverter type
  - Intra-Stage Diversion
- Geo-Engineered Completions
  - Cluster placed in “Like Rock”
  - Understand in-situ stress and NWBFP
  - Stress Shadowing

Perforation Efficiency



90 deg Phasing” orientated
(Normal Cross Section)

- Perforation damage zone
- Inconsistent hole size
- Perf tunnel restrictions
- Perf injection profile
- Zero degree phasing
- Extreme Limited Entry
- Perforation Erosion

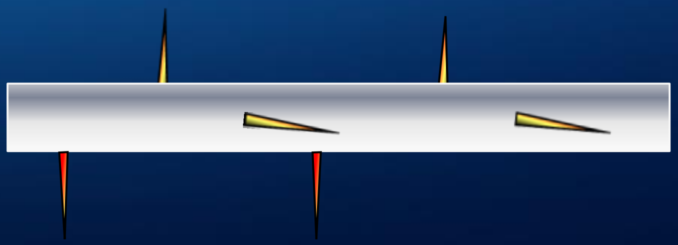


Illustration of hole size and Gun Offset effects of decentralized guns

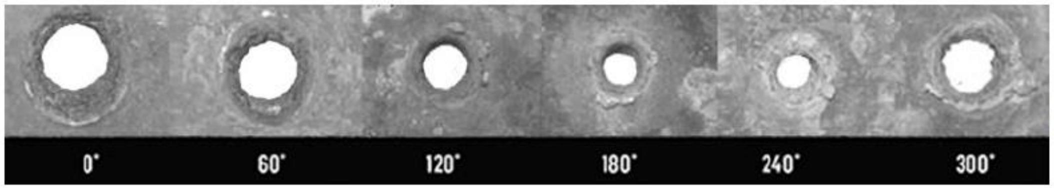
Perforation Gun Phasing with oriented guns

Oriented guns can help
obtain predictable hole size

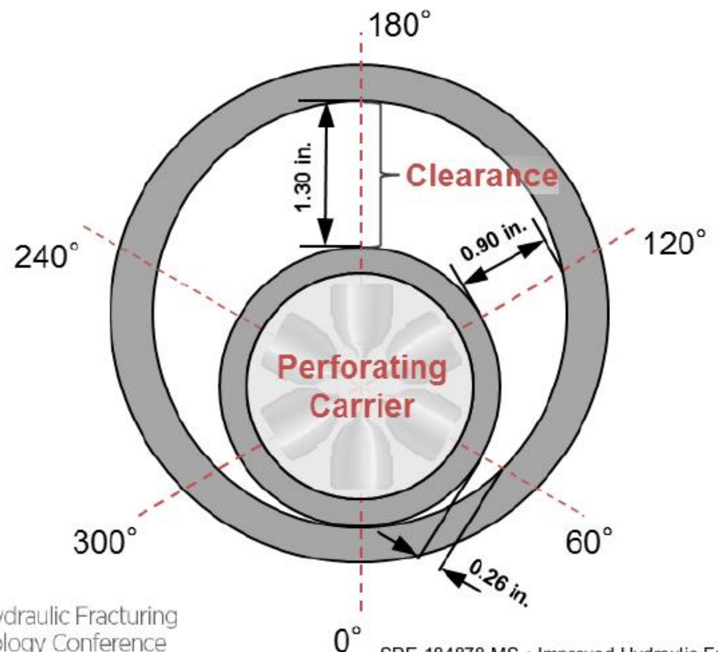
Illustration of hole size and perforation phasing of decentralized guns

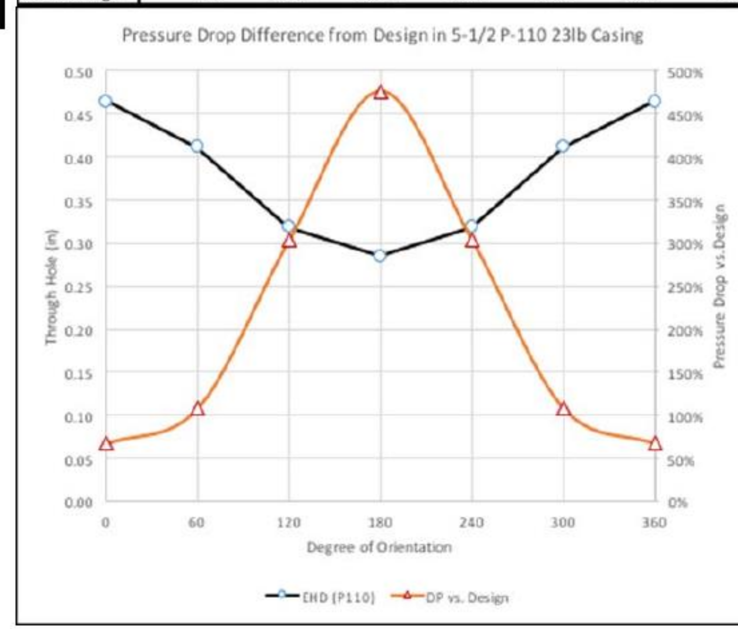
Conventional Perforating Systems

CONVENTIONAL PERFORATING SYSTEMS

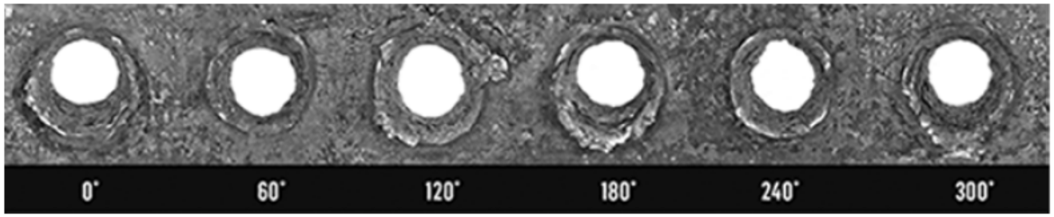


Shot No.	1	2	3	4	5	6	7
Phase	0	60	120	180	240	300	360
Clearance	0.00	0.26	0.90	1.30	0.90	0.26	0.00
API EHD	0.42	0.42	0.42	0.42	0.42	0.42	0.42
EHD (P110)	**0.46**	**0.41**	**0.32**	**0.28**	**0.32**	**0.41**	**0.46**
DP vs. Design	67%	109%	304%	477%	304%	109%	67%



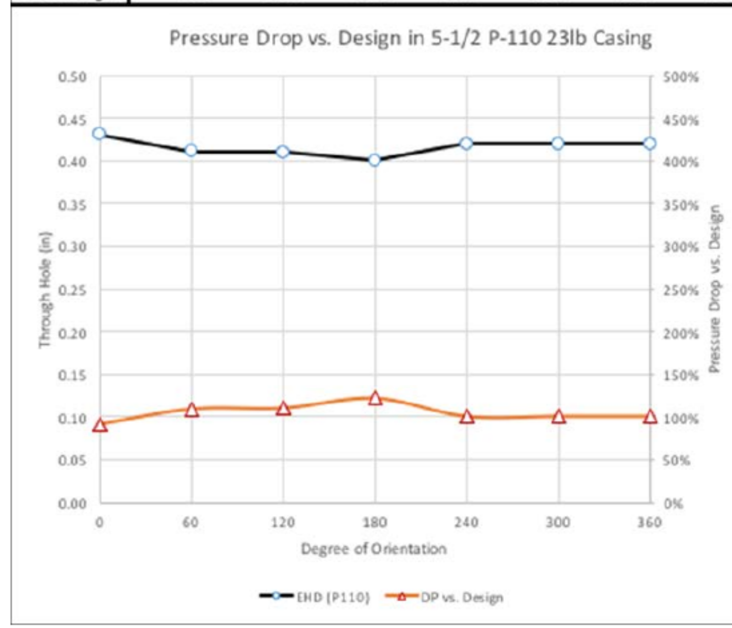


CONSISTENT PERFORATING SYSTEM

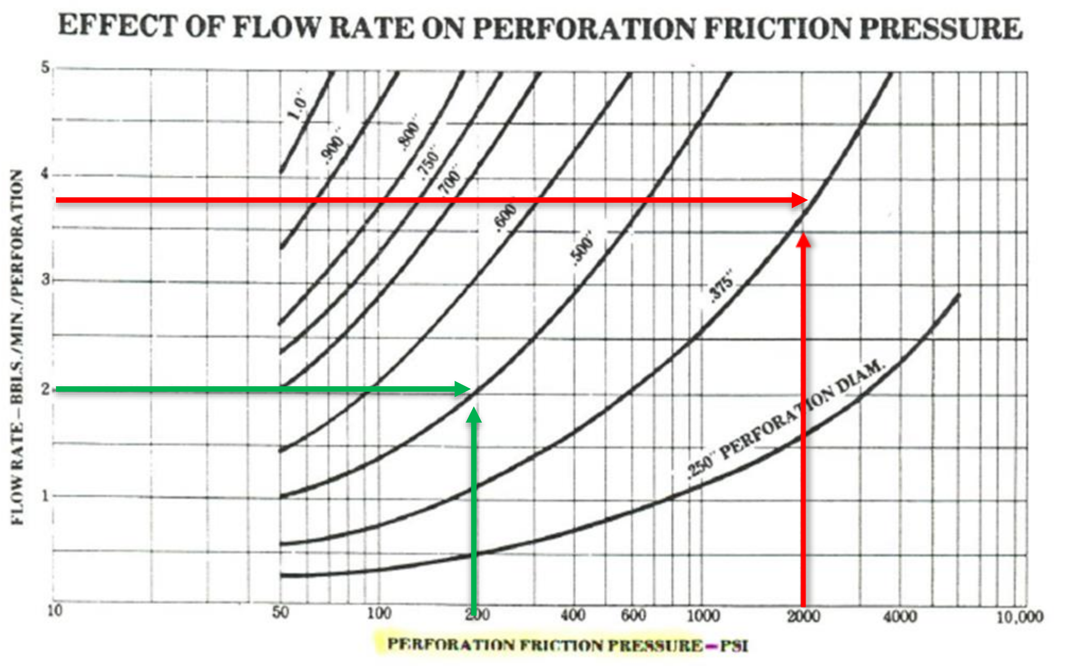


- Entrance hole diameter
  - Predictable and constant in a range of casing sizes, weights, and grades (eg. 4-1/2 – 5-1/2 P-110)
- Penetration
  - Variation in clearance does not impact the penetration

Shot No.	1	2	3	4	5	6	7
Phase	0	60	120	180	240	300	360
Clearance	0.00	0.26	0.90	1.30	0.90	0.90	0.90
API EHD	0.42	0.42	0.42	0.42	0.42	0.42	0.42
EHD (P110)	**0.43**	**0.41**	**0.41**	**0.40**	**0.42**	**0.42**	**0.42**
DP vs. Design	91%	109%	110%	122%	100%	100%	100%



Limited Entry



BJ Hughes Handbook

- Limited entry is an attempt to assure total zone coverage during stimulation
- Limited entry may be enhanced through diversion by limiting fluid flow into adjacent perforations throughout the treatment, but it may also limit production.
- Extreme limited entry may lead to perforation erosion

Balance between limited entry and erosion

Downhole Image Showing Perforation Erosion

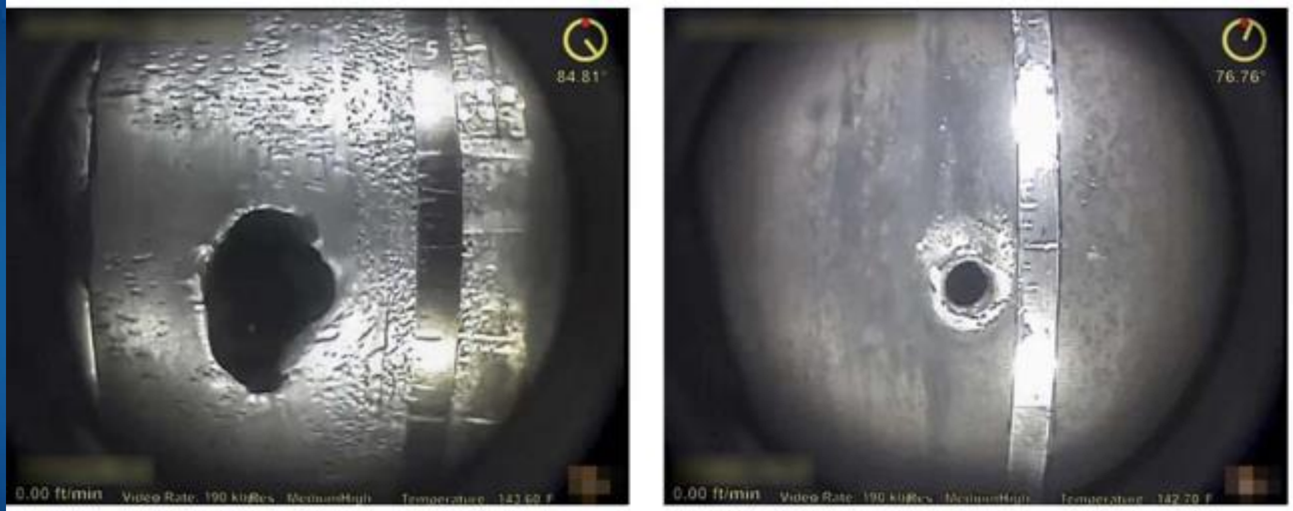


Figure 15—Post-treatment images of heavily eroded (low side) and minimally eroded (high side) perforations from the same well. Orientation of the charges with respect to circumferential position is often a contributing factor in post-treatment dimensions.

SPE-194334-MS, Cramer HFTC 2019

Geometric vs. Geo-Engineered

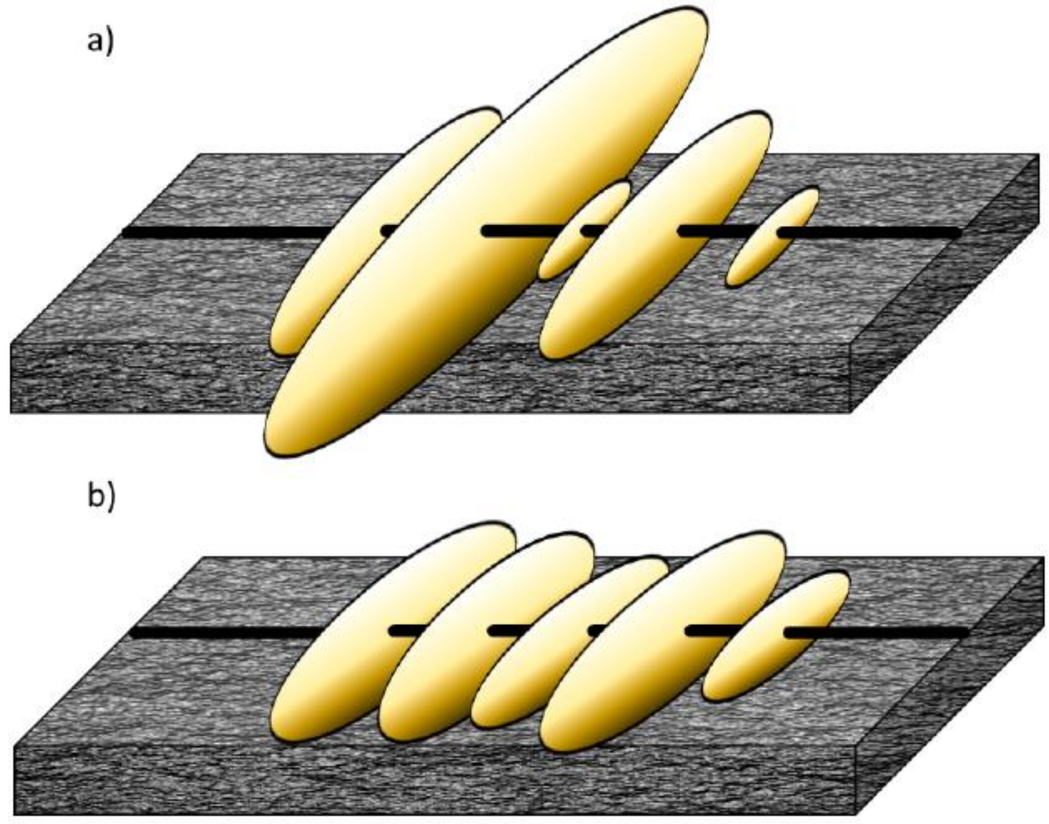


Figure 4: Geometric Completions (a) are more likely to create highly conductive, dominant "super fracs" while Engineered Completions (b) tends to provide better reservoir coverage

https://www.linkedin.com/pulse/why-some-engineered-completions-fail-kevin-wutherich

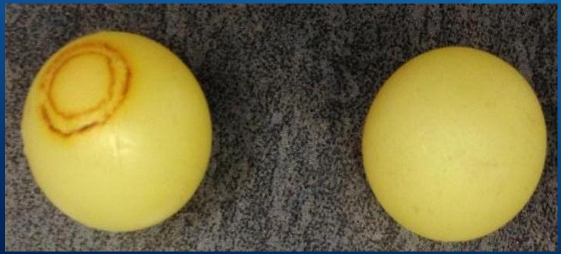
Evolution of Multi-Cluster Diversion Technology

- Rock Salt, Benzoic Acid Flakes, Proppant Slugs
- Sliding Sleeves
- Single Point Injection – CTA Fracturing and Abrasive Jet Perforating
- Plug and Perf
- Limited Entry
- Extreme Limited Entry
- Ball Sealers, Biodegradable Ball Sealers (PLA)
- Small mesh PLA material
- POD Diversion

Diverting Agents

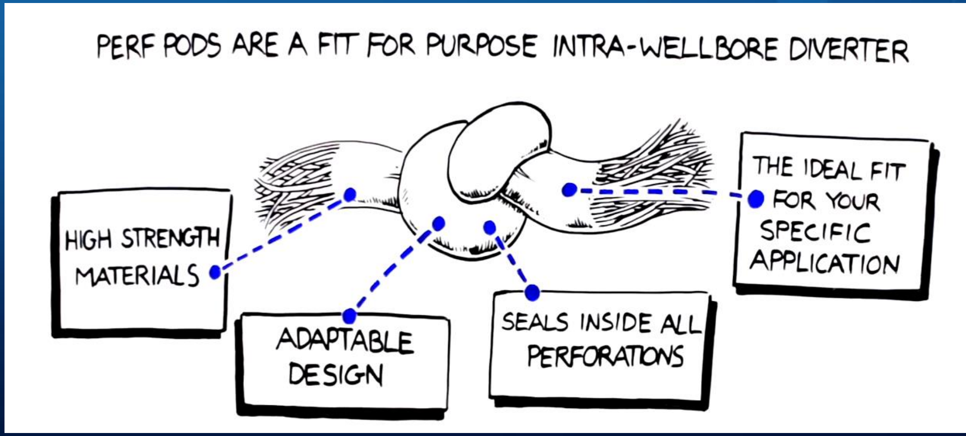
Rubber coated nylon balls

Bio-degradable balls (PLA)



Bio-degradable PLA Mesh
(8 / 40 / 100 mesh)

POD Diversion



POD Pod Diversion Test (0.50” perf holes)

4.5” casing w/ 2 x 0.5” perf holes at 4 bpm – 600 psi perf friction

POD Diversion

- Serve as miniature frac plugs
- Can eliminate the need for frac plugs
- 1: 1 perforation seal efficiency ratio
- Can be more reliable than conventional frac plugs
  - frac plugs have a documented history of up to 40% failure rate when measured with fiber optic (DAS / DTS) SPE 2171506
- Thermally Degradable or millable
- Diminish drill out and wellbore cleanup time
- Stay in the flow stream during the treatment to assure proper lateral coverage
- Stay on seat until they dissolve or removed

Acrylic Flow Loop Demo

Dynamic flow illustration – 8 bpm - real-time

Conventional vs. Extreme Limited Entry

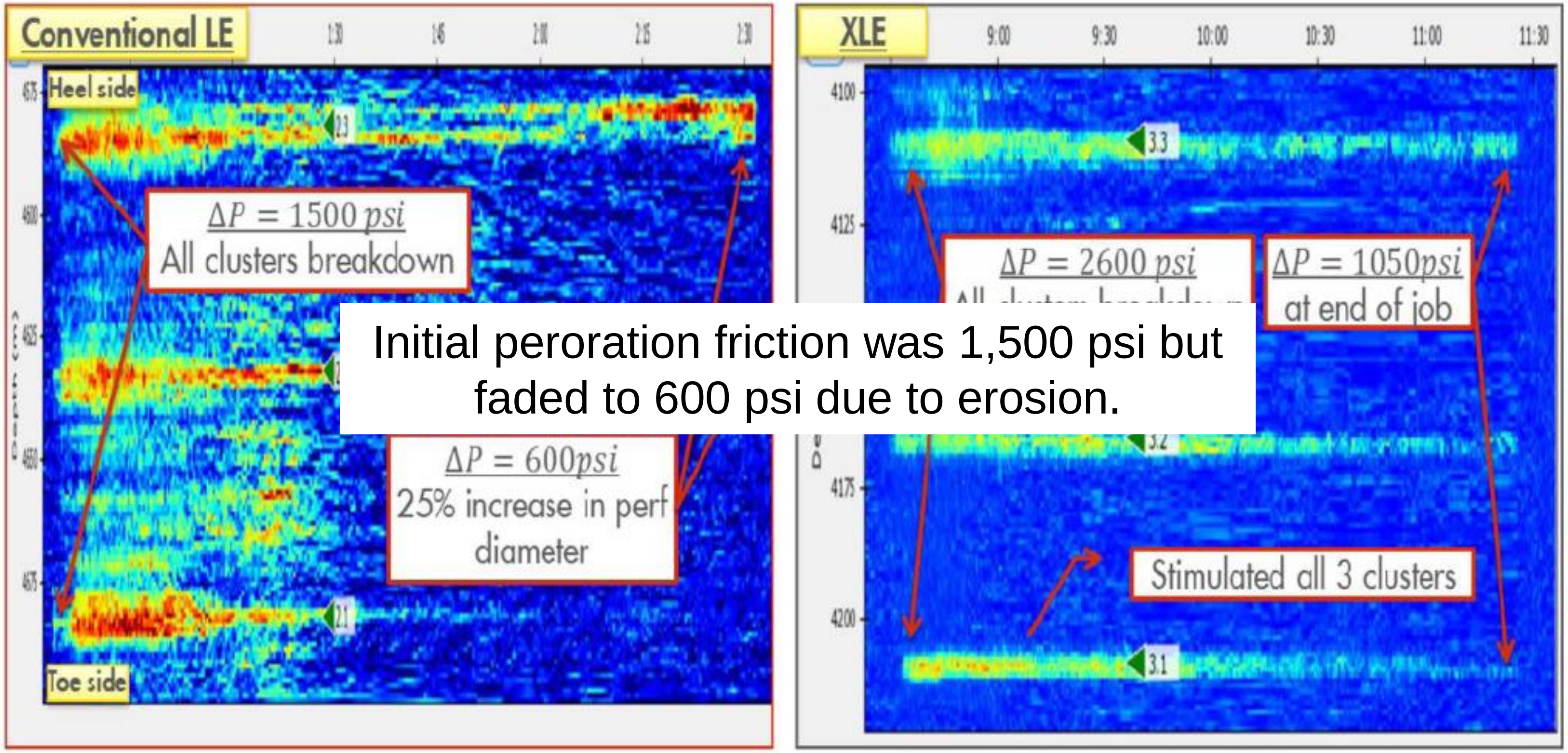
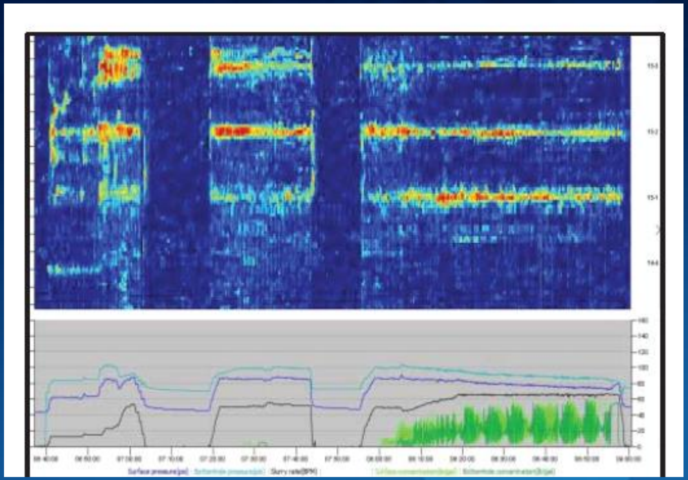


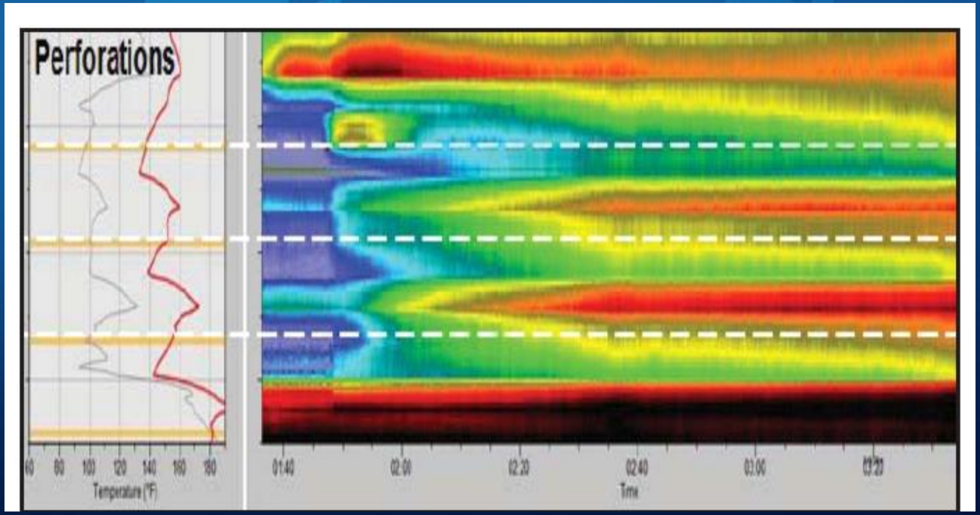
Figure 7— The "XLE" waterfall plot on the right shows that the toe-side cluster 3.1 is connected throughout the treatment. The nominal acoustic fading towards end of frac is more likely visual. As perforations erode, the acoustic noise shifts into lower frequency bands causing it to look like the connection is "fading".

Three Cluster Limited Entry Design



DAS acoustic activity while pumping shows each cluster taking fluid and sand through the duration of the stage..

DTS post job warm-back showing each cluster taking a significant amount of fluid



Plugless Completion

2 Well Study – Greene County, PA

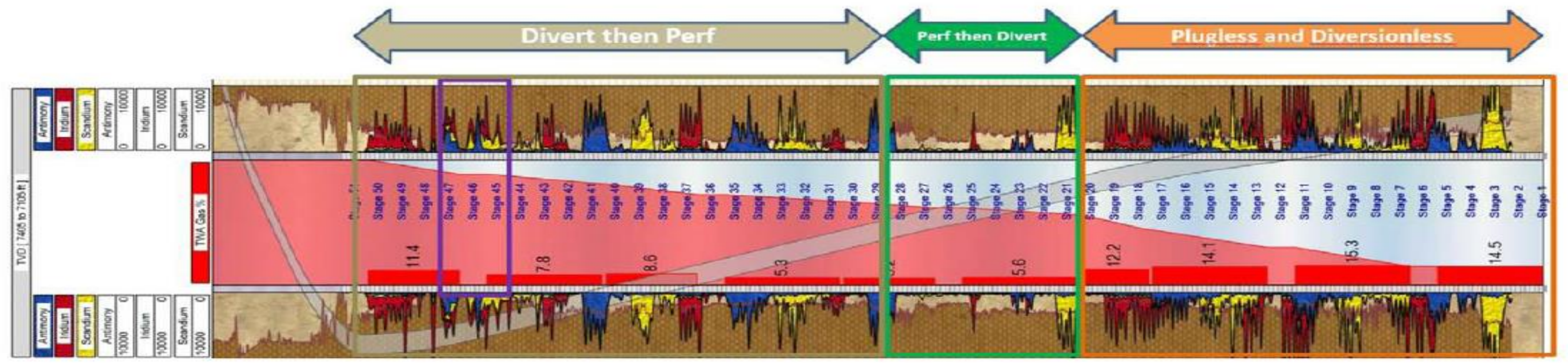


Figure 12—Marcellus 1H log plot with gas tracer returns percentage and proppant tracers.

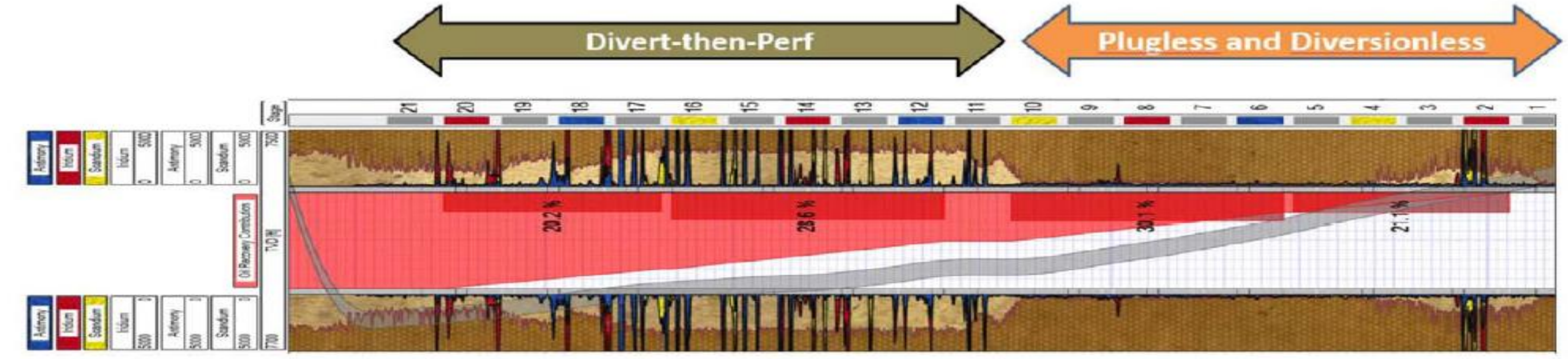


Figure 22—Burkett 1H Log with gas tracer returns percentages and proppant tracers.

Plugless Completion - Production

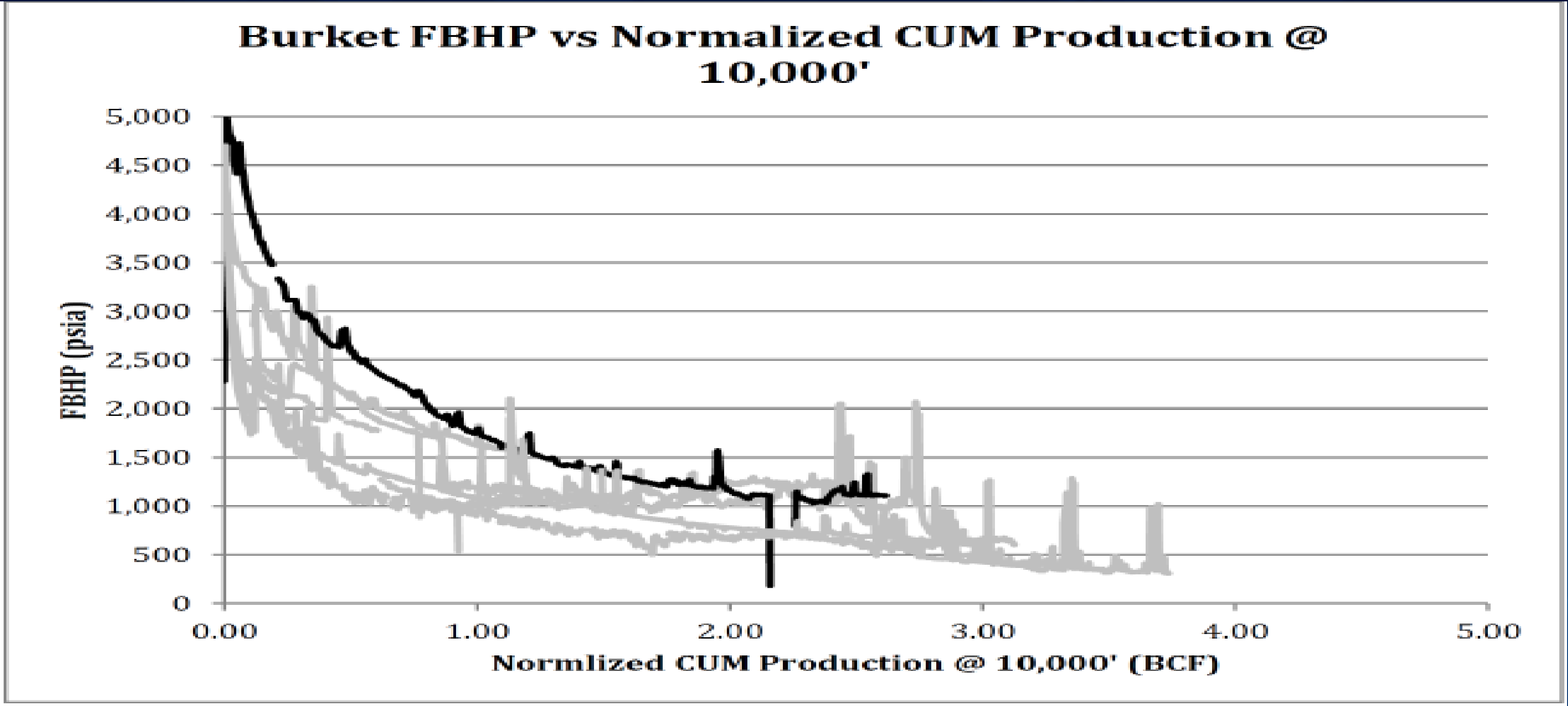


Figure 26—Burkett flowing bottomhole pressure vs normalized cumulative production to 10,000 ft lateral length.

- Above average production compared to offsets within 5 mile radius

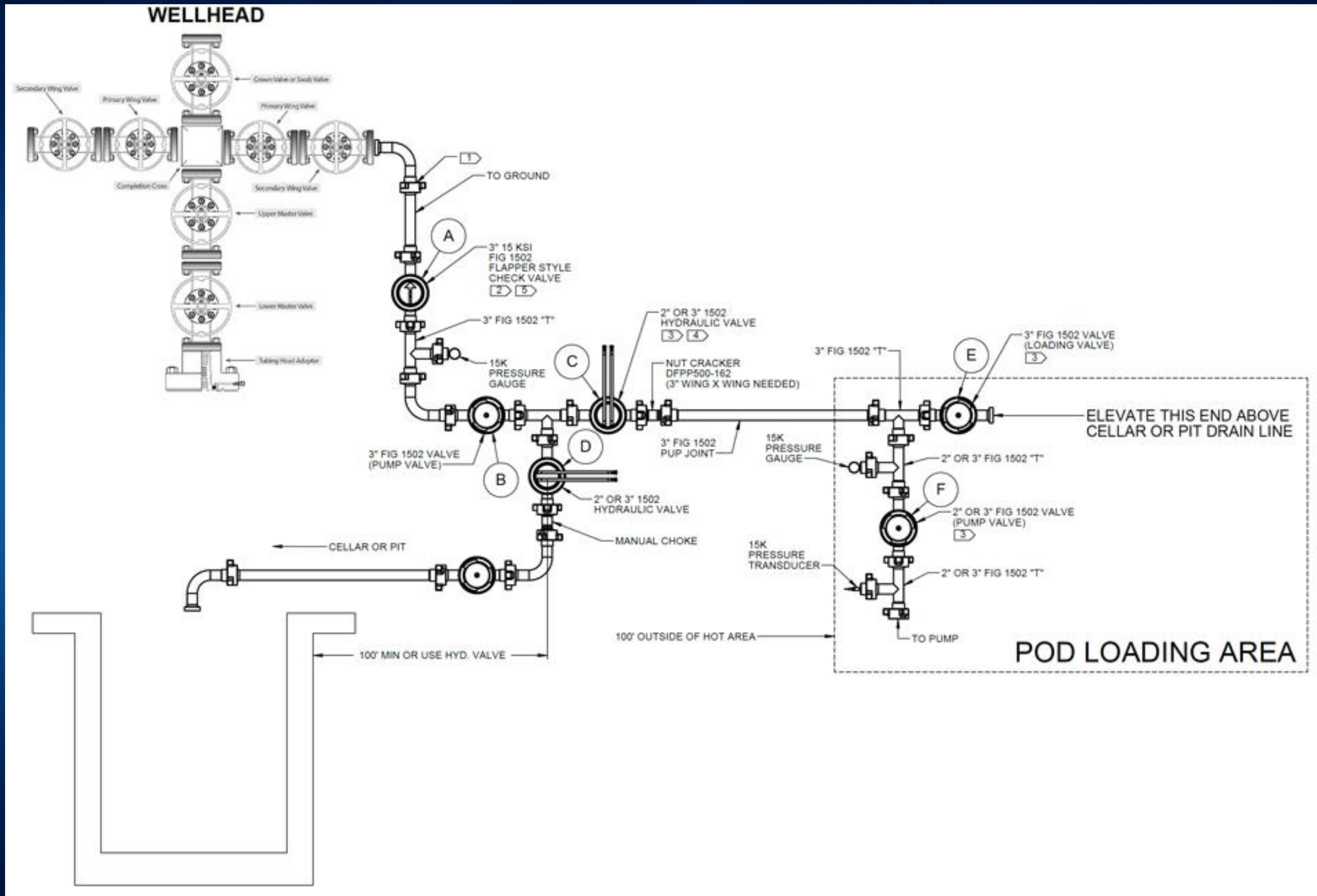
Recommendations and Considerations

- Divert & Perf - Operationally
  - Leave open enough perforations for subsequent pump-down at desired rate
  - Seat PODs and achieve max surface pressure at minimal rate reduction
  - Perform “soft” shutdown on pumps to minimize water-hammer effect
- Divert & Perf – Trial
  - Full well trial to compare production results with offset
  - Partial well trial to evaluate effectiveness of POD isolation
    - Recommend at least 10 stages to obtain substantial data set
- Full Stage Isolation
  - Use POD Wireline Deployment
    - Drop PODs from surface and plug remaining perforations with Wireline Deployment

Deployment Methods

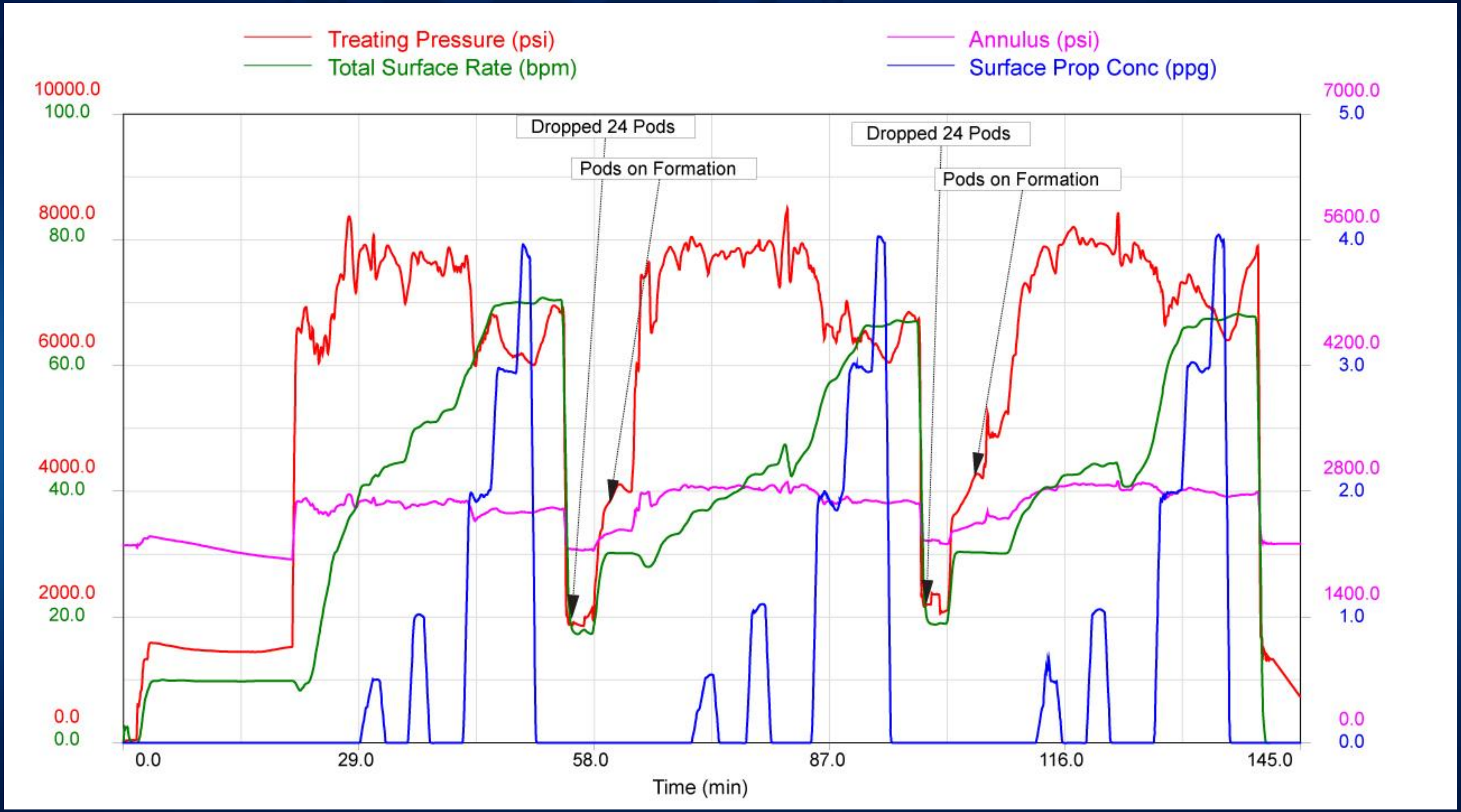
- Ball Drop System
- Auger System
- Wireline – Baker 10 - Setting tool

POD Ball-Drop Style System



Auger Deployment System

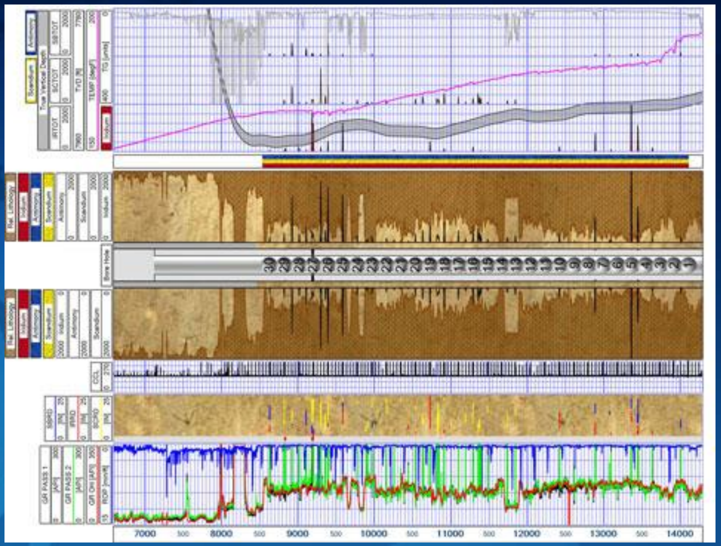
Case Study – Cottage Grove Formation, Custer County, OK



Case Study No. 6202

PODs Divert Multistage Sleeve System for Successful Re-Frac

DETAILS:



Click to enlarge…

- Formation: Bakken
- Operation Depth: 13,710' – 14,400'
- POD Type: PCL-Large Millable PODs
- Type of Operation: Horizontal Re-Frac

RESULTS:

- Added new perforations between existing sleeves
- Same Perf PODs were used to plug sleeves and new perforations
- Radioactive tracer showed diversion throughout entire lateral with stimulation to sleeves and new perfs

Case Study No. 6202

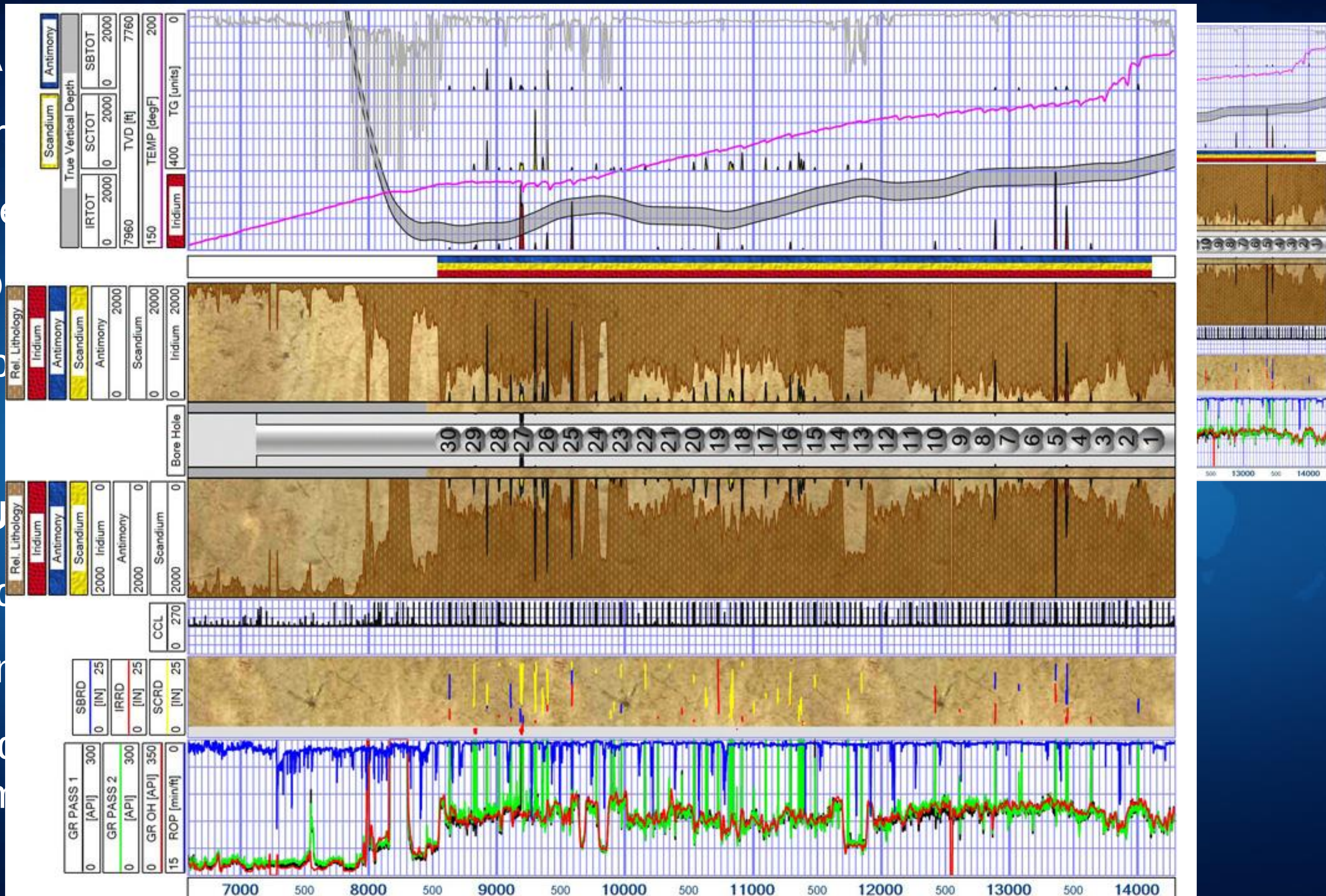
PODs Divert Multistage Sleeve System for Successful Re-Frac

DETA

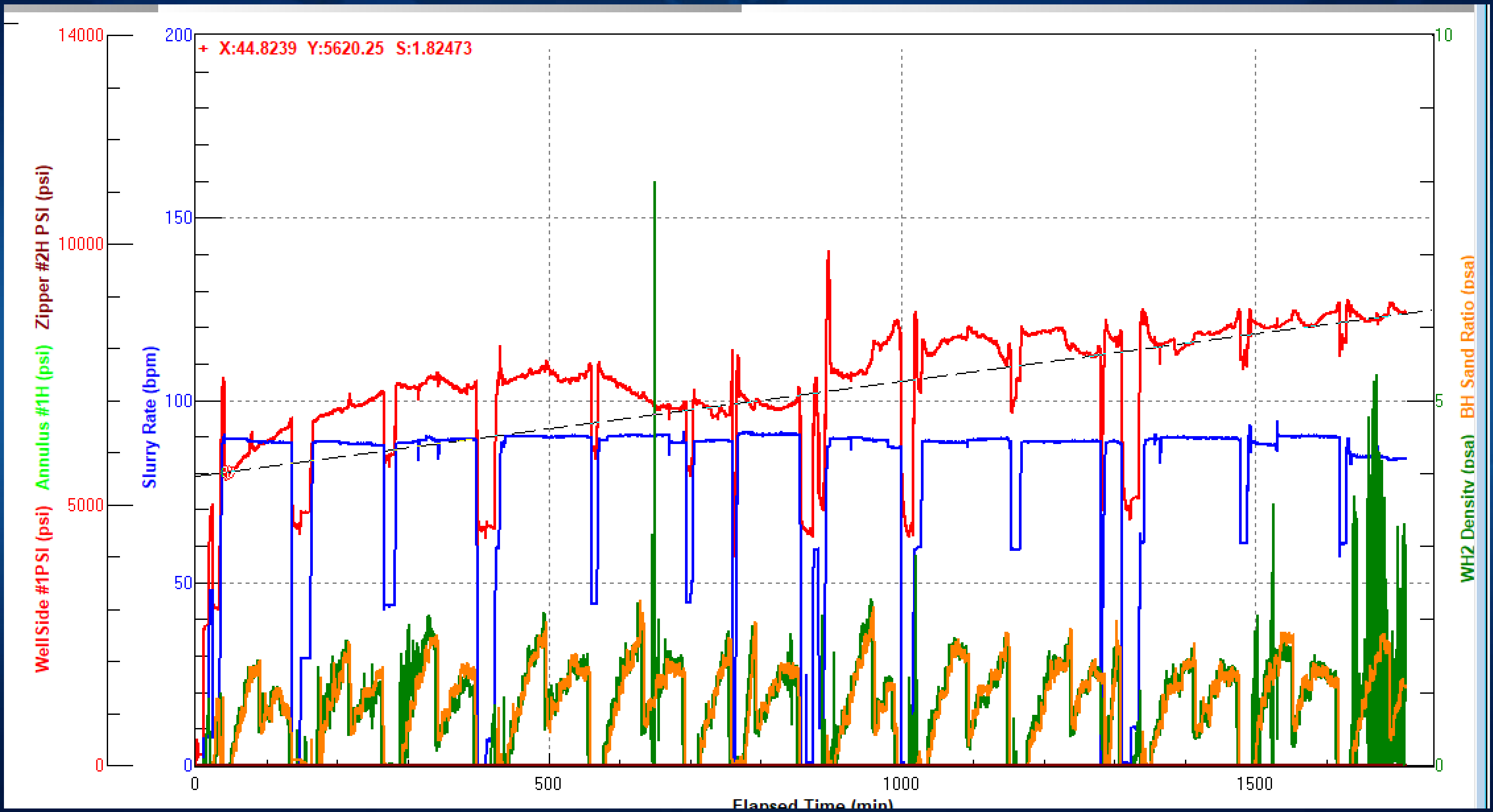
- For
- Ope
- PO
- Typ

RESU

- Add
- San
- Rad stim

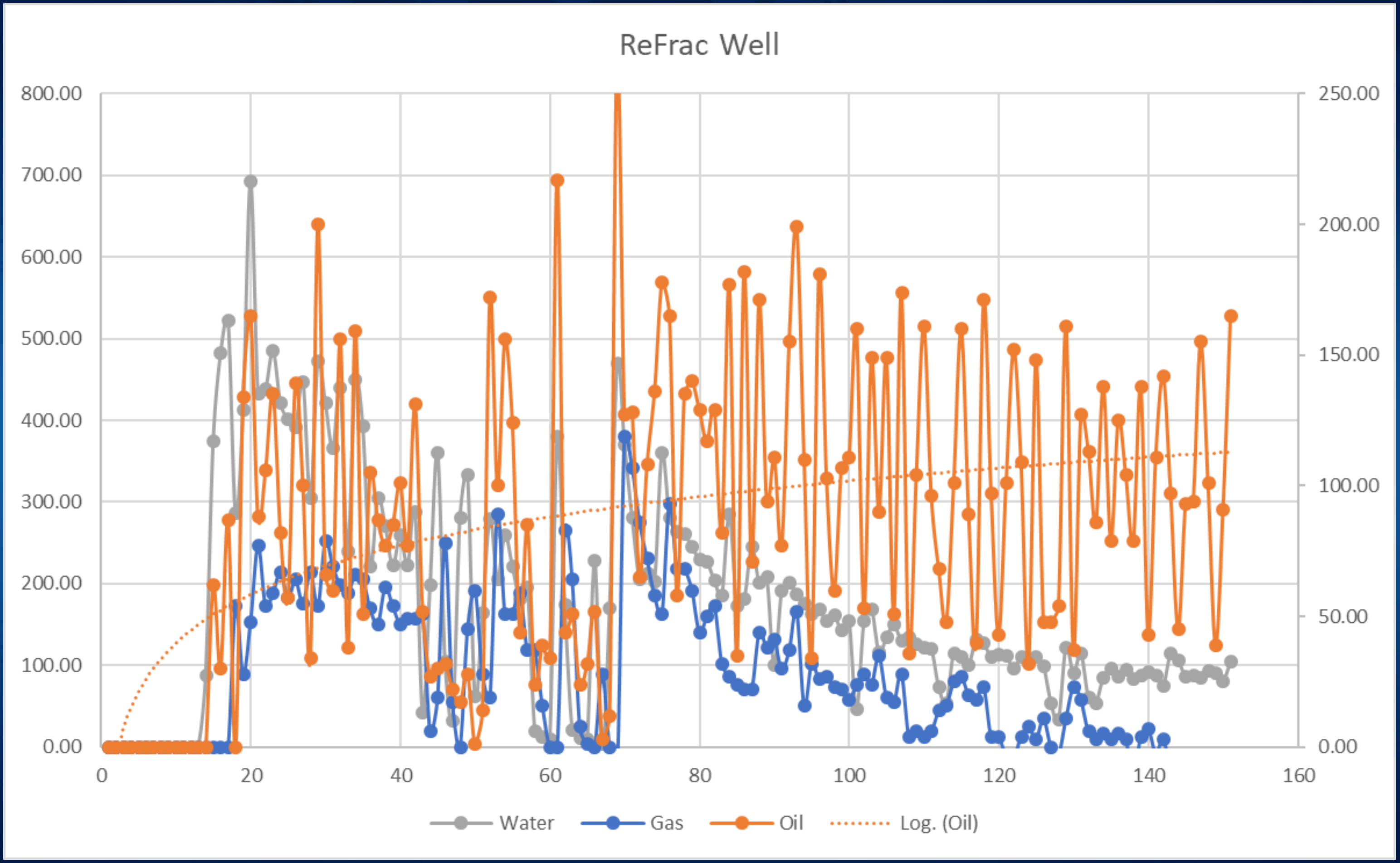


Eagle Ford POD ReFrac

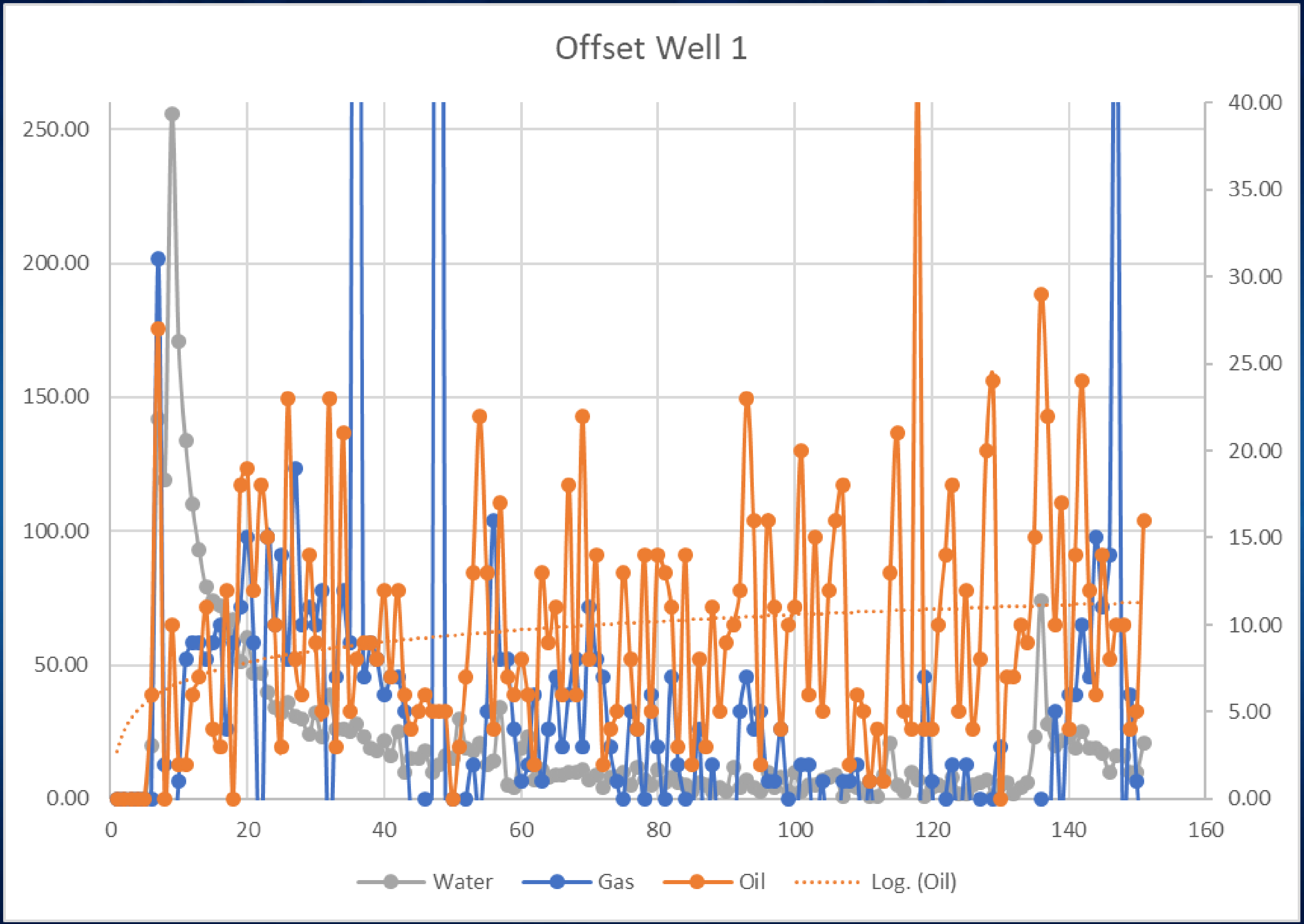


Westside SPE Luncheon
February 20, 2019

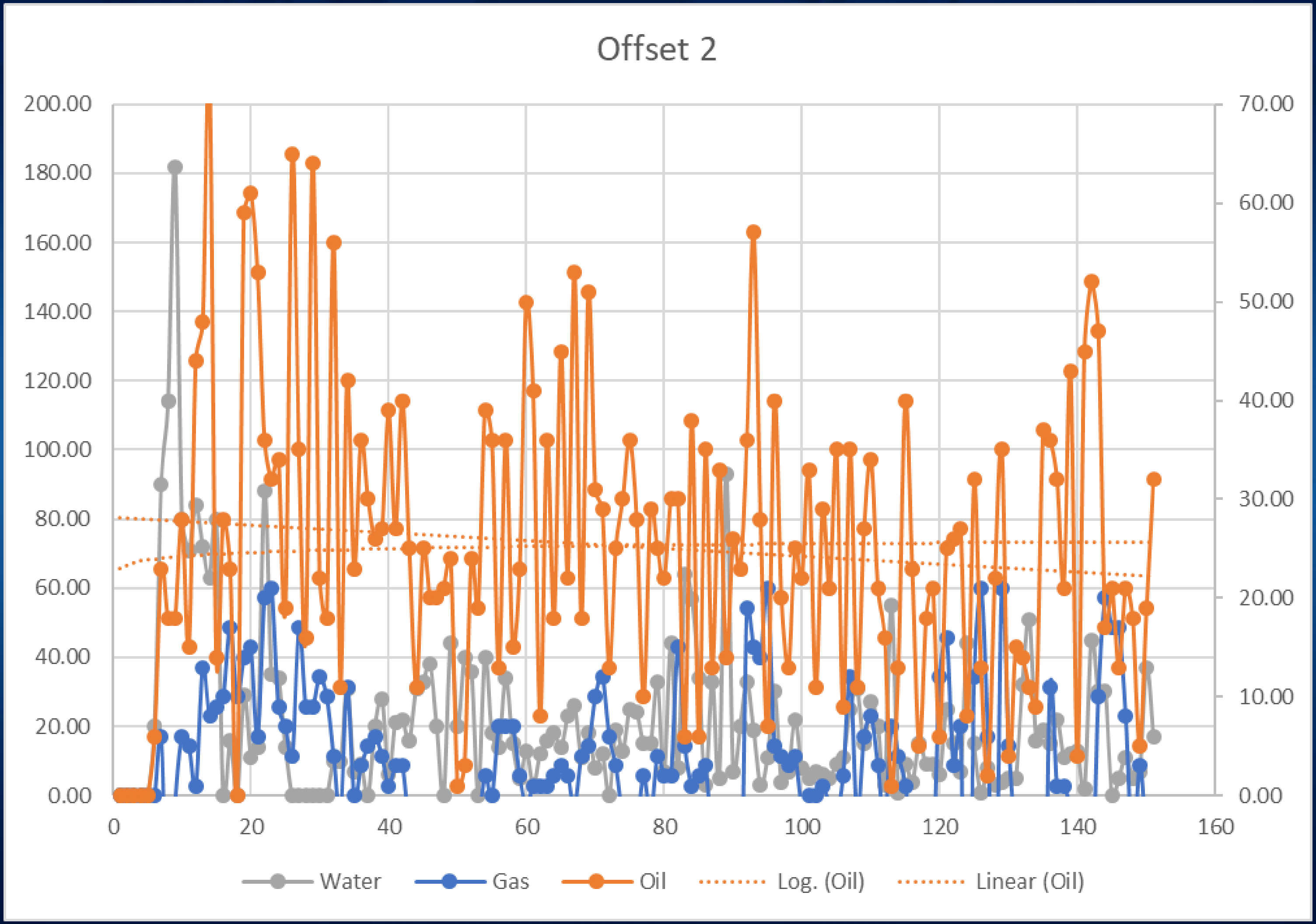
ReFrac Production



Offset Well 1 Production



Offset Well 2 Production

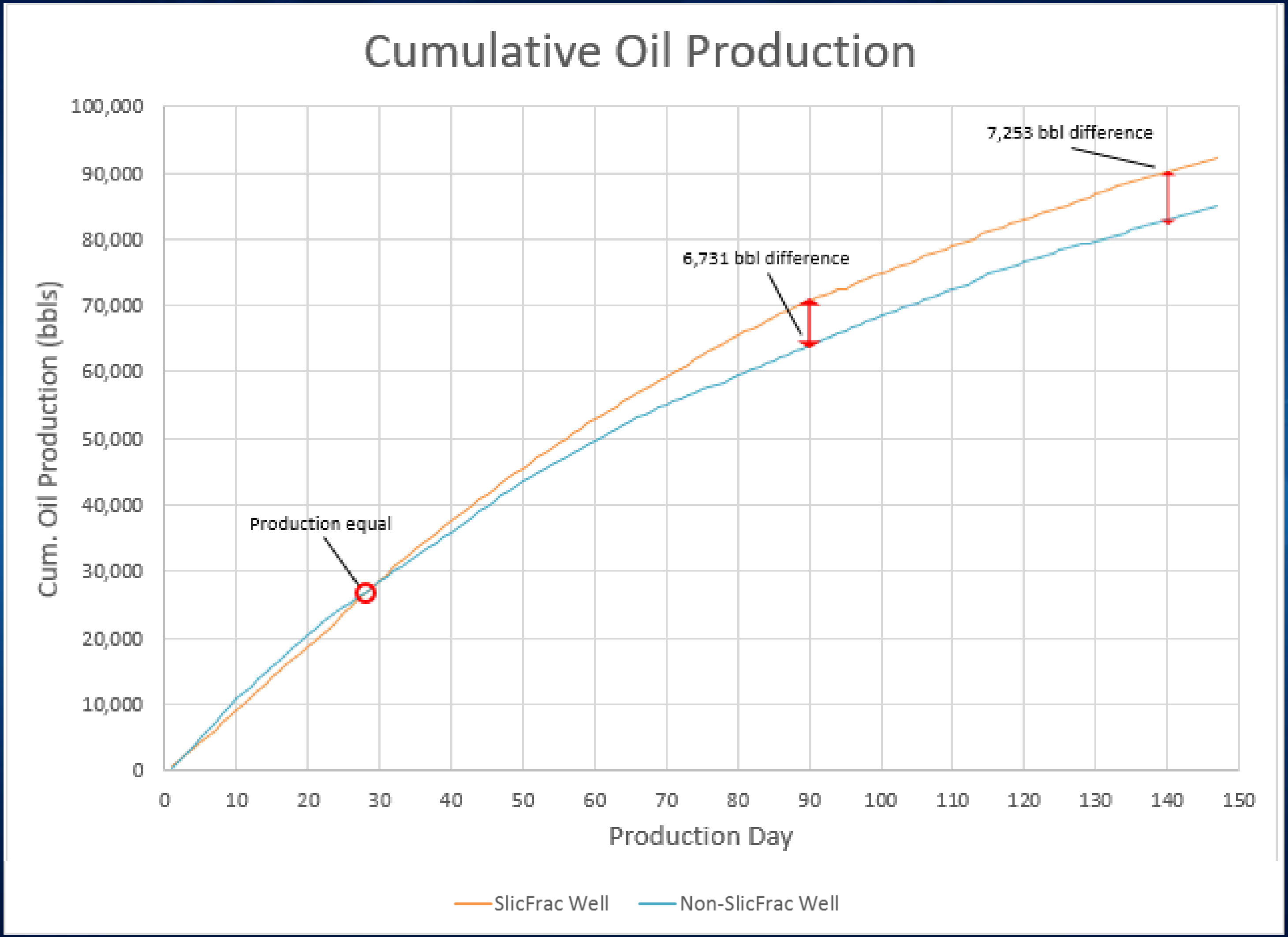


POD Diverter Test - Irregular Perforations

Go to http://www.slicfrac.com/resources
to see videos and case studies prsented

Erosion can diminish the ability of some diverter systems to seal

Intra-Stage POD Diversion Production Comparison



Karnes County, TX

Technology Update

- 1,298 Total Jobs
- 32,900 Stages
- 1,025 Plug & Perf Interstage Diversion Jobs
- 36 Pod & Perf
- 92 Horizontal ReFracs
- 65 Vertical Refracs
- 696,400 PODs
- 1,995 Frac Plugs Eliminated
- 160 Operators

Summary

POD Diversion Opportunities

- Extend fracture stages in horizontal wells
- Eliminate or reduce the number of frac plugs required
- Higher perforation seal ratio compared to conventional material
- Thermally degradable to reduce or mitigate well-bore clean-out time
- Stay in the flow path during the treatment (path of least resistance)
- Fit for purpose in ReFracs
- Can be used where casing restrictions prohibit frac plugs

Closing Thoughts

- Begin with the end in mind
- Understand expected treating pressure
- Have a good understanding of fractures and NWBFP
- Calculate expected perforation friction pressure

Acknowledgements

- SPEGSC
- Thru Tubing Solutions
- Jeff Whitworth and Cody Trebing TTS
- David Cramer, ConocoPhillips
- Friends and Colleagues

Questions?

POD Diversion References

- HFTC SPE 189900-2018; Diversion Optimization in New Well Completions; ProTechnics (PODs)
- URTeC : 2902114-2018 ; Rapid Evaluation of Diverter Effectiveness From Poroelastic Pressure Response in Offset Wells; Linn Energy, Reveal Energy Services (PODs)
- URTeC 2888446-2018; New Mexico Delaware Basin Horizontal Well Heel Frac and Refrac Program and Hydraulic Fracture Diagnostics; ; OXY (PODs)
- HFTC SPE-194331 2019; Continuous Use of Fiber Optics-Enabled Coiled Tubing Used to Accelerate the Optimization of Completions Aimed at Improved Recovery and Reduced Cost of Development; Oasis – PODs vs. PLA
- HFTC SPE-189880-2018; Mining the Bakken II — Pushing the Envelope with Extreme Limited Entry Perforating; Liberty Resources
- HFTC SPE-194374; An Eagle Ford Case Study: Improving an Infill Well Completion Through Optimized Refracturing Treatment of the Offset Parent Wells; Nobel (POD-ReFrac)

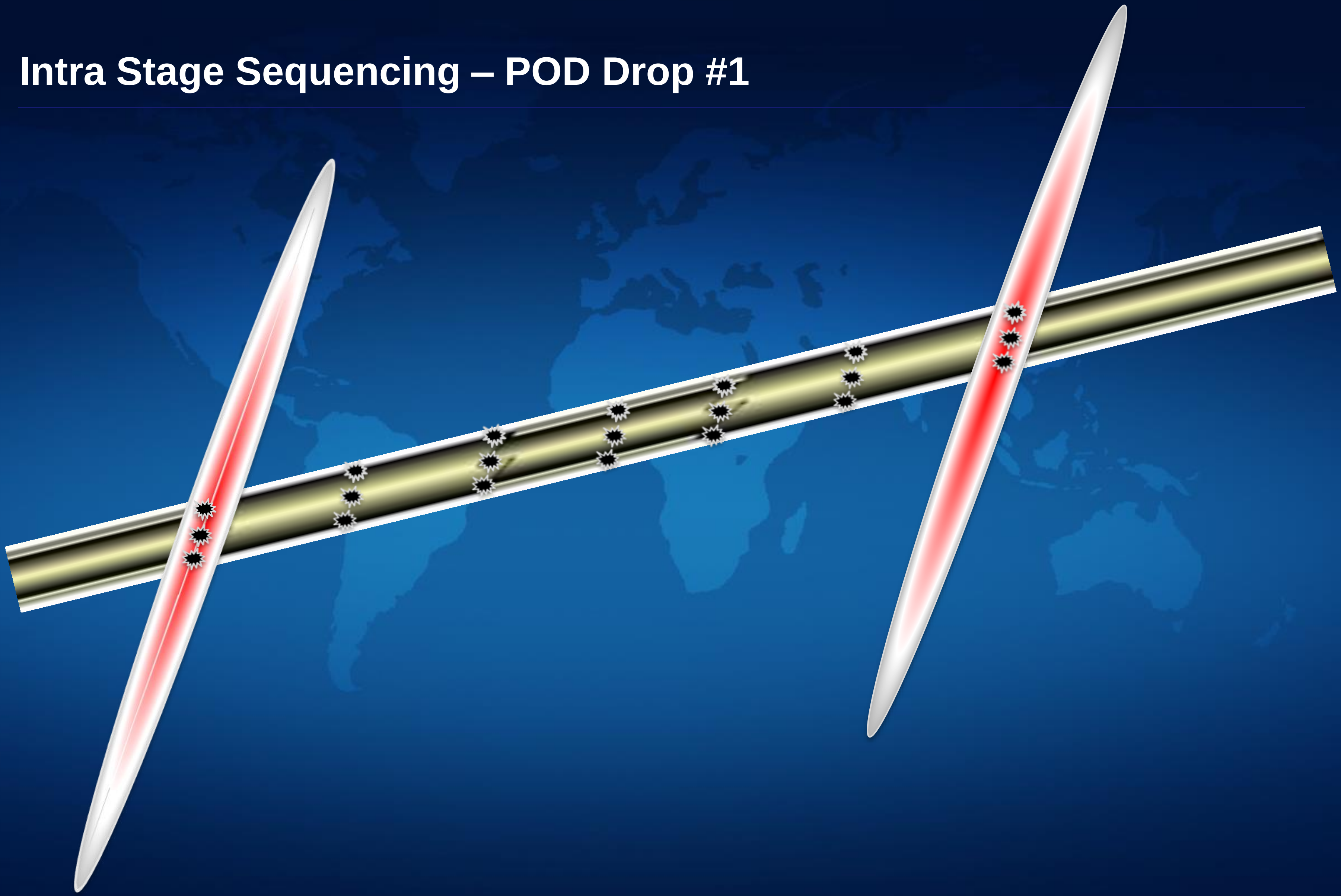
Additional References

- URTeC: 2171506-2015 ; An Integrated Dataset Centered Around Distributed Fiber Optic Monitoring – Key to the Successful Implementation of a Geo-Engineered Completion Optimization Program in the Eagle Ford Shale; BP (Plug Failures)
- HFTC SPE-184834-MS 2017; Extreme Limited Entry Design Improves Distribution Efficiency in Plug-n-Perf Completions: Insights from Fiber-Optic Diagnostics; (Shell)
- HFTC SPE 168607-2014; Re-fracturing Horizontal Shale Wells: Case History of a Woodford Shale Pilot Project;, (BP)
- SPE 173348-2015; Challenging Assumptions About Fracture Stimulation Placement Effectiveness Using Fiber Optic Distributed Sensing Diagnostics: Diversion, Stage Isolation and Overflushing; HFTC (Shell)
- SPE 103232 ATCE 2006; A Field Study Optimizing Completion Strategies for Fracture Initiation in Barnett Shale Horizontal Wells; Devon Energy; (Stress Shadowing)

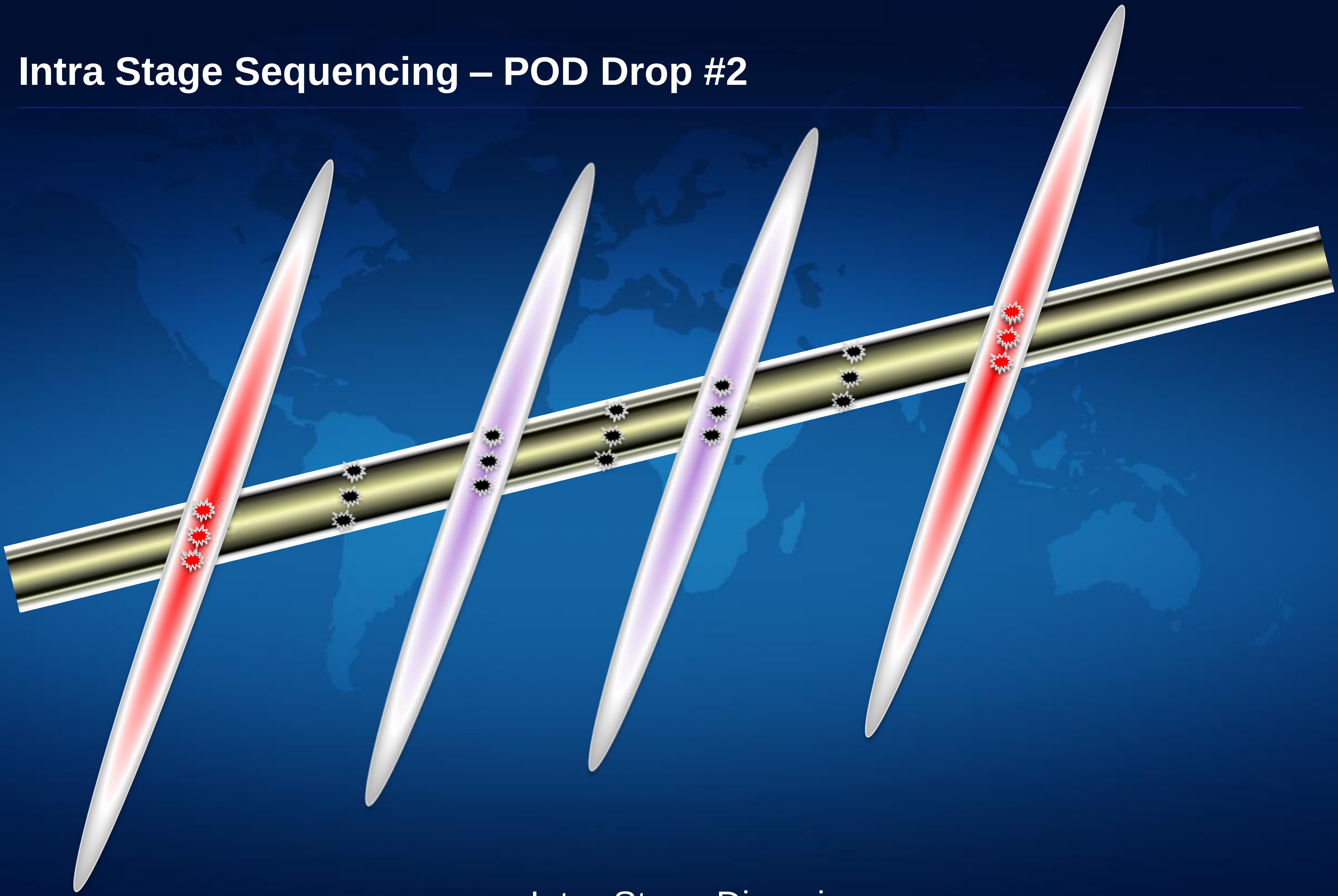
Additional References

- HFTC SPE-194329 2019; Utilization of Far Field Diverters to Mitigate Parent and Infill Well Fracture Interaction in Shale Formations; Conoco
- HFTC SPE-194334 2019; Integrating DAS, Treatment Pressure Analysis and Video-Based Perforation Imaging to Evaluate Limited Entry Treatment Effectiveness; Conoco, Cramer
- HFTC SPE-194354 2019; Child Well Analysis from Poroelastic Pressure Responses on Parent Wells in the Eagle Ford; Reveal, SM Energy
- HFTC SPE-194371 – 2019; New Near-Wellbore Insights from Fiber Optics and Downhole Pressure Gauge Data; Shell – Canada (Fiber Optic)
- SPE-191781-18ERM-MS 2019; Plugless Completions Techniques and Evaluation in the Appalachian Basin; CNX, ProTechnics

Intra Stage Sequencing – POD Drop #1

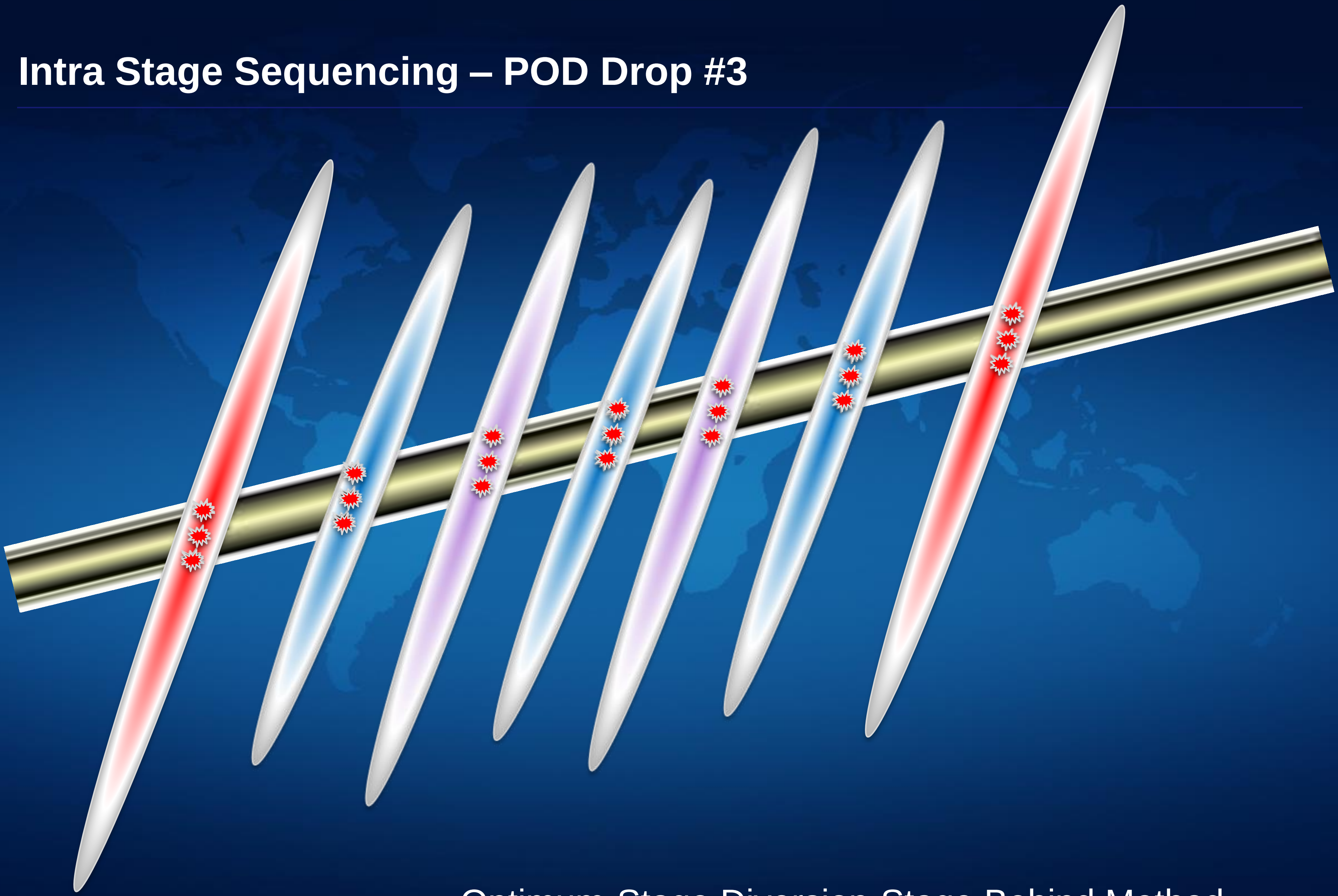


Intra Stage Sequencing – POD Drop #2



Intra-Stage Diversion

Intra Stage Sequencing – POD Drop #3



Optimum-Stage Diversion-Stage Behind Method