Perforating for Hydraulic Fracturing Next Generation Technologies for Unconventional Completions

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Introduction

The Ultimate Goal of Perforating Unconventional Completions

- Optimize the fracturing treatment
  - Make sure proppant is diverted into every cluster.
  - Reduce or eliminate tortuosity
  - Reduce or eliminate competing fracture systems

Introduction

- Properties Affecting the Fracture Orientation and Growth:
  - Rock Properties
  - Bedding Planes
  - Artificial Barriers
  - Pore Pressure
  - Net Pressure

Perforations have a strong impact on these factors

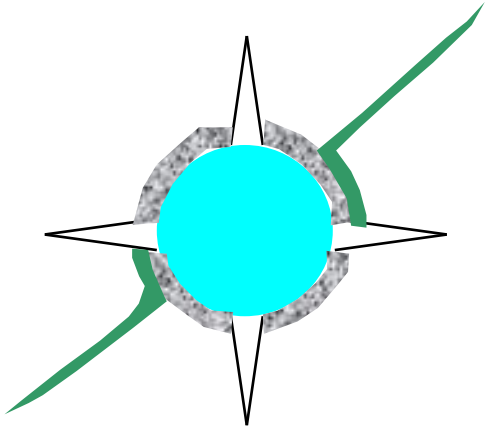
- Perforations are Near-Wellbore Friction Sources:
  i. Perforation Friction, influenced by: Diameter, Number and Discharge coefficient
  ii. Fracture Tortuosity
  iii. Multiple Fractures.

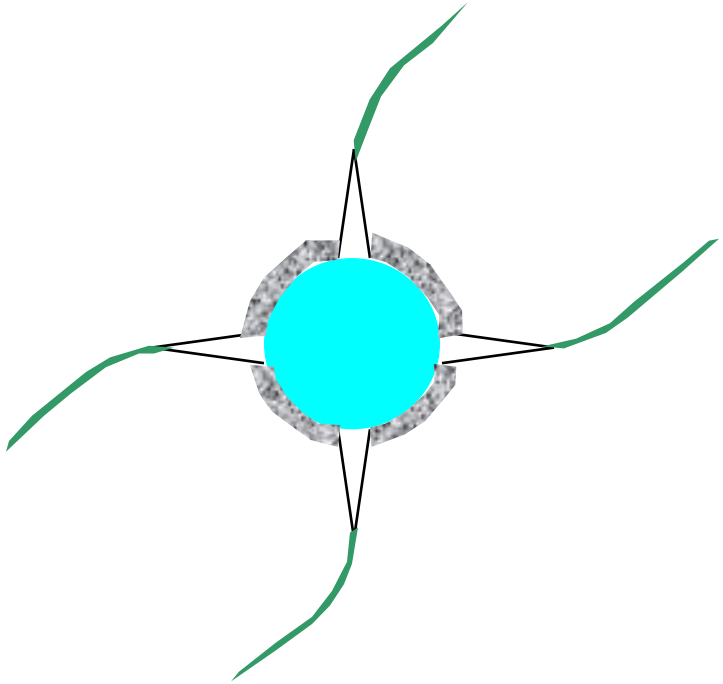
Current systems address (i) by optimizing the number of shots and diameter.

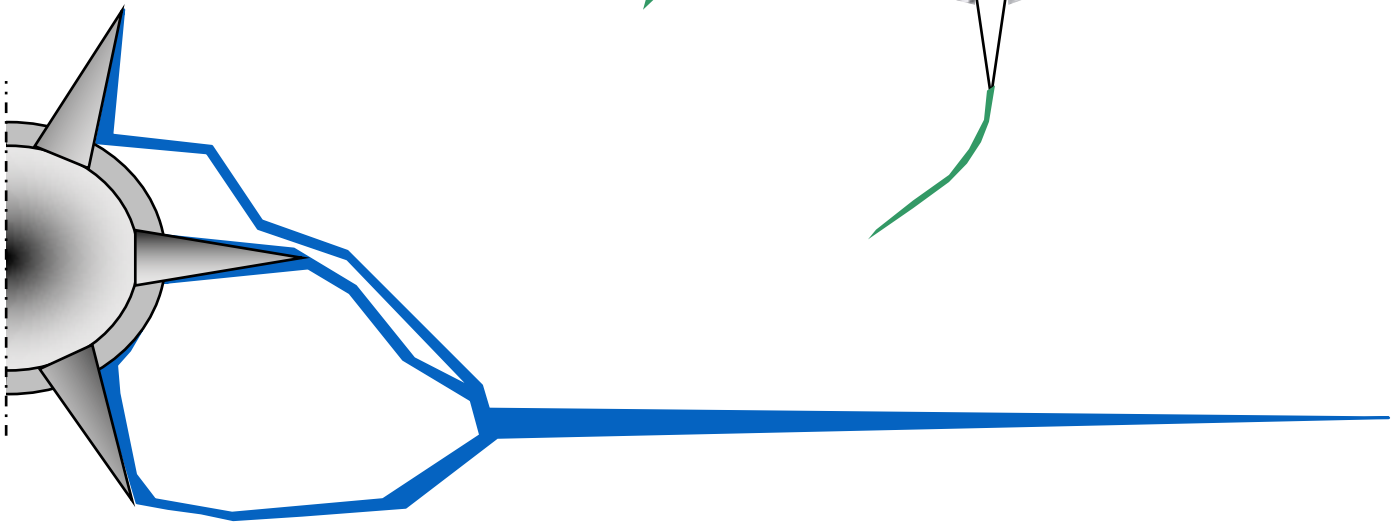
Systems to assist in reducing tortuosity, and eliminating near wellbore multiple fracture width restrictions are rather limited….

Tortuosity

- Deviated Wells
  - Slanted well-bore causes fracture twisting
- Poor Depth of Perforation Penetration
  - Very poor well-bore communication
- Perforation Phasing Misalignment
  - phasing misses minimum horizontal stress
- Long Perforated Intervals
  - Multiple fractures may initiate
- Naturally Fractured Reservoirs
- Formations With Very High Leak-off
  - Created fracture width too narrow
- When Using Newtonian Fracturing
  - Narrow width generation



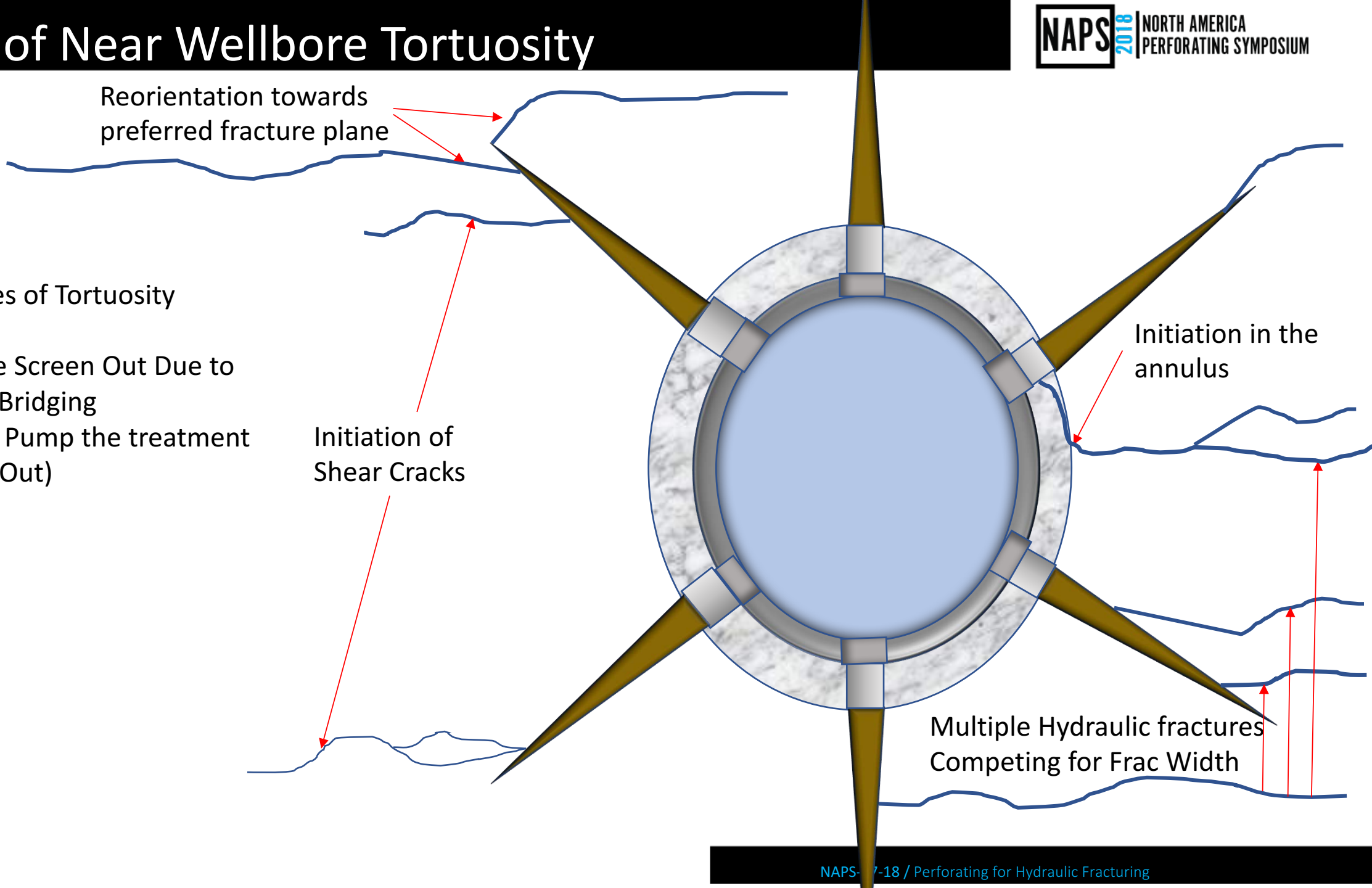




Causes of Near Wellbore Tortuosity

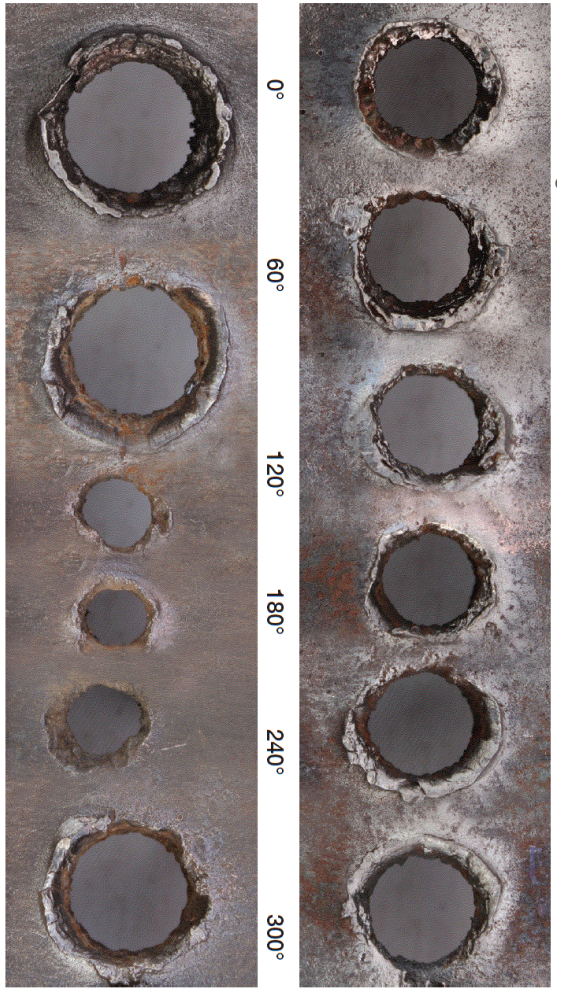
Consequences of Tortuosity

- Premature Screen Out Due to Proppant Bridging
- Unable to Pump the treatment (Pressure Out)



Frac Optimized Charges

- Uniform hole size
  - -improved distribution of treating fluids
  - -reduced friction and tortuosity
  - -more efficient sand distribution
  - -assists with cost reductions
- Quicker Ramp up to treating pressures
- Reduced variation in flow area.



Frac Optimized Charges

- Uniform hole size probably does not do all the things that are claimed.
- EHD changes very quickly due to erosion once injection rates are established, especially those perforations nearest the plane of principal stress.
- Once the fluid stream goes from turbulent to laminar flow, the erosion will stop.
- **Uniform EHD takes the perforation out of the equation, after that it's the reservoir that will dictate fracture success**.
- They probably help minimize screenouts.

Frac Optimized Charges

Why These Specific EHD Numbers

- For most of the software used in the industry, these are the EHD numbers used for fracture design.
- Any change in EHD makes the result look odd, in a “cookie cutter” operation, deviation from normal is not a good thing.
- Once the fracture begins, EHD can increase in some perforations by over 100%
- Assumptions are made as to how many perforations are actually open and actual EHD at bottom hole conditions.

This Is Why Hole Size is Important

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Design Rate	100		Perf Diameter	0.25
TVD of Lateral	10000		Pipe Grade	80
Fluid Specific Gravity	1.001		Perf Coefficient	0.65
Specific Gravity Override				

Desired Rate per Perf

Cluster Mid Perf	Fracture Gradient	% Flu Desire
9950	0.75	16.6%
10000	0.75	16.6%
10050	0.75	16.6%
10100	0.8	16.6%
10150	0.7	16.6%
10200	0.75	16.6%

Adjust Percentages to Tot

Design Rate	100		Perf Diameter	0.35
TVD of Lateral	10000		Pipe Grade	80
Fluid Specific Gravity	1.001		Perf Coefficient	0.65
Specific Gravity Override			Diameter Coefficient	0.829

Desired Rate per Perf: 2

Cluster Mid Perf	Adjusted Bottom Hole	Calculated	Adjusted Bottom Hole Treating
9950			
10000			
10050			
10100			
10150			
10200			

Adjus

Design Rate	100		Perf Diameter	0.42
TVD of Lateral	10000		Pipe Grade	80
Fluid Specific Gravity	1.001		Perf Coefficient	0.65
Specific Gravity Override			Diameter Coefficient	0.829

Desired Rate per Perf: 2

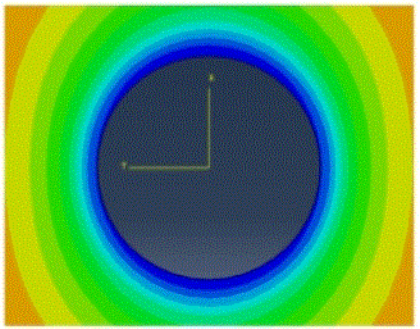
Cluster Mid Perf	Fracture Gradient	% Fluid Desired	BHFP	Differential Pressure Desired	Adjusted Bottom Hole Treating Pressure	Rate	Calculated Perfs Required	Resulting Differential	Adjusted Bottom Hole Treating Pressure Rate/Perf
9950	0.75	16.6%	7462.5	1500	8962.5	16.6	6	797.8222	8260.3222
10000	0.75	16.6%	7500	1500	9000	16.6	6	797.8222	8297.8222
10050	0.75	16.6%	7537.5	1500	9037.5	16.6	6	797.8222	8335.3222
10100	0.8	16.6%	8080	1500	9580	16.6	6	797.8222	8877.8222
10150	0.7	16.6%	7105	1500	8605	16.6	6	797.8222	7902.8222
10200	0.75	16.6%	7650	1500	9150	16.6	6	797.8222	8447.8222
					Total Perfs Needed =>		36		

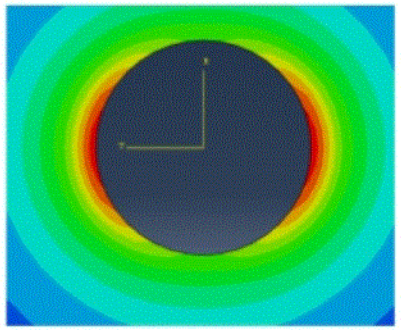
Adjust Percentages to Total 100%

- The more perforations required, the greater the chance for competing fractures, bridging and screenouts

So What is Important?

- It is important that the shaped charge can penetrate beyond the hoop stress boundary around the wellbore. 8-10 inches minimum.
- Uniform EHD takes the perforation out of the equation, so to speak.
- It's important to remember the EHD is only important until laminar flow is created.
- Typically perforations within 30° of the stress plane take the bulk of the fluid and sand.



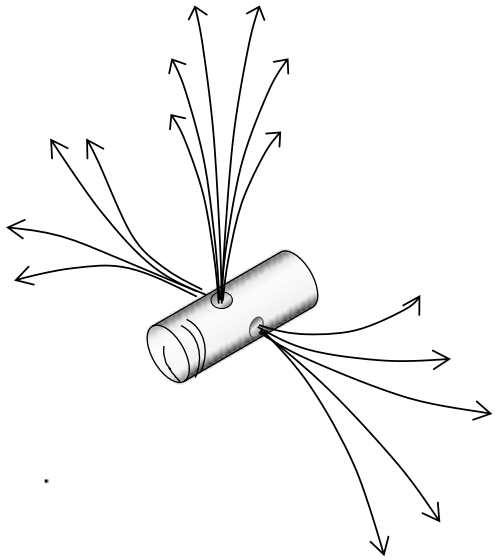


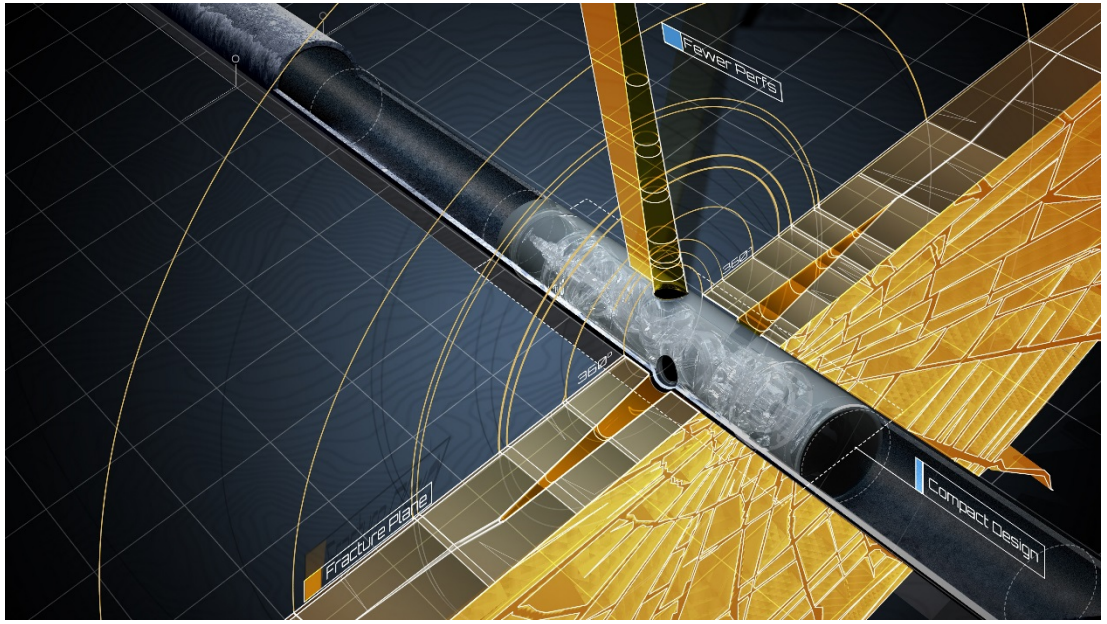
Develop a System

Develop a frac-optimized system that optimizes the fracture treatment and improves reservoir access in unconventional wells.

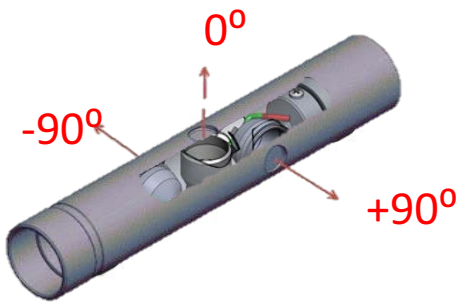
Key drivers:

- Fewer perforations
- Axial consolidation of flow area and orienting the flow entry to the high side of the lateral.
- Compact and Efficient design
- Improved Reliability



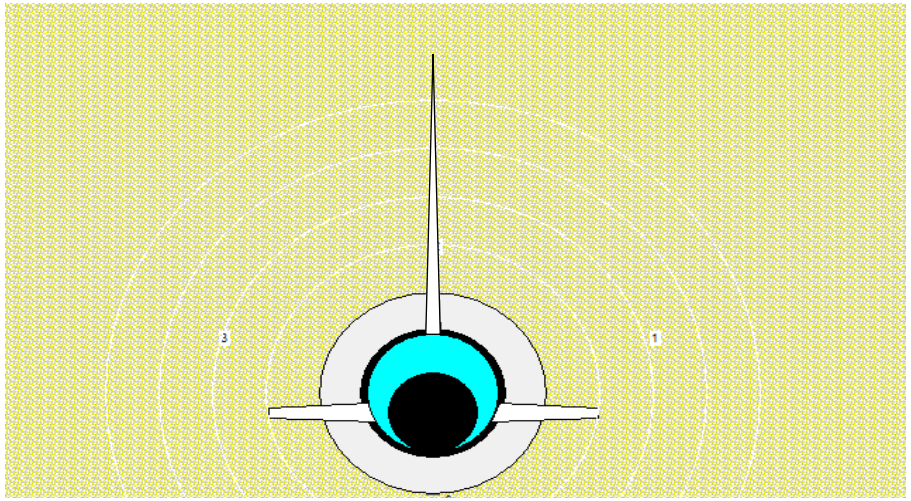


System Development



Phase	Hole Size Average	Current System Hole size	Penetration	Current System Penetration
-90°	0.3” - 1”	**0.91”**	4”-23”	**5.0”**
0°	0.3” - 1”	**0.33”**	4”-23”	**23.0”**
+90°	0.3” - 1”	**0.91”**	4”-23”	**5.0”**

- Gun length 18 in.
- Spacing between charges 1.4 in.
- Three shaped charges
- Two big hole charges on the sides, Deep Penetrator on the high-side
- Gun Sizes: 3-1/8” and 3-3/8”



Frac Optimized System

Video Goes Here

Case Study

			Avg. FOS	Avg. CON	% DIFF
Breakdown	STP	(psi)	9180	9498	-3.5%
	Slurry rate	(BPM)	56.5	50.6	10.3%
Pad	STP max	(psi)	9482	9832	-3.7%
Pad & Initial Proppant Stage	Time to Full Rate	(min)	12.2	16.4	-35.1%
Proppant Stages	Total avg. mass rate	(lb/min)	5386	5135	4.7%
	Avg. slurry rate	(BPM)	94.0	90.0	4.3%
	STD dev slurry rate	(BPM)	2.04	3.72	-82.3%

- During breakdown stage, FOS exhibited a 300 psi reduction in breakdown pressure even at a 10% increase of injection rate.
- 35% decrease in time required to reach full, as designed, injection rate.
- Increase in proppant mass rate of 250 lb/min.
- 4 BPM increase in average slurry rate during proppant stages
- 82% decrease in standard deviation of injection rate during proppant stages, indicating an increase in rate stability.

Conclusion

A Perforating Strategy is Critical to Fracturing Success

- Design the system to eliminate competing fracture systems
- Use the charge that will penetrate past the hoop stress
- Consider other perforating strategies to optimize the frac.

QUESTIONS? THANK YOU

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