NEXT SHALE 2017

Organized by: dmg::events

Navigating the Future of Unconventional Resources

UNIQUE LIMITED ENTRY CLUSTER PERFORATING SYSTEM IMPROVES FRACTURING EFFICIENCY IN HORIZONTAL WELLS

David Cuthill, GEODynamics, Inc.

GEODynamics®

NS17 - 042

AGENDA

- Cluster Perforating for Limited Entry Stimulation
- Conventional Perforating Systems
- Constant Entry Hole & Constant Penetration
- Radial Plane Perforating Systems
- Angled Perforating Systems
- Conclusions

INTRODUCTION

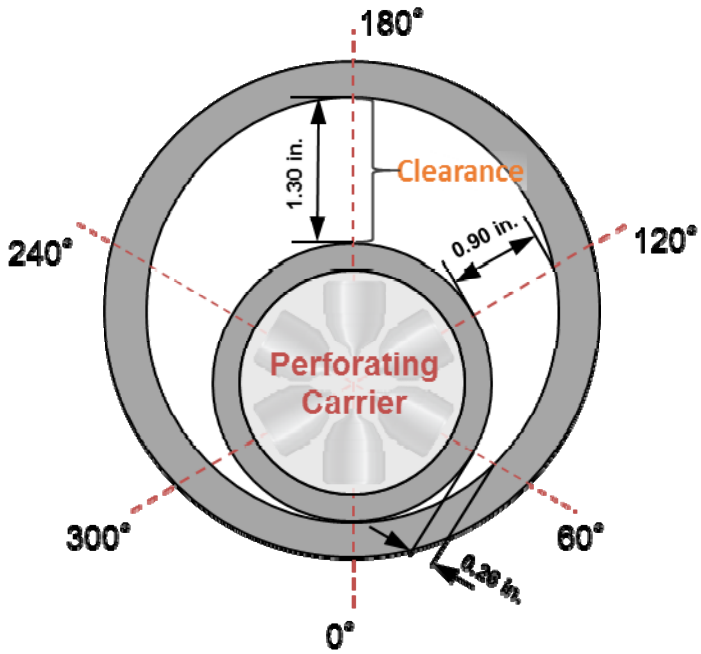
- Vertical well perforating tools have been successfully adapted to horizontal wireline plug and perforation applications
- Limited consideration is given to the impact perforating configuration may have on subsequent operations conducted on the well
  - Perforation phasing, orientation, geometry, & clear tunnel length
- New learnings have pushed operators to new techniques
  - 2 - 4 shot, 6 - 8 shot, or 10 - 12 shot clusters predominantly
  - Stages of 40 – 90+ per well
  - Cluster spacing as tight as 15 ft (had been 100 ft or more)
  - Clusters trending towards >8 per stage
- Awareness that perforating tools may need modification

LIMITED ENTRY STIMULATION

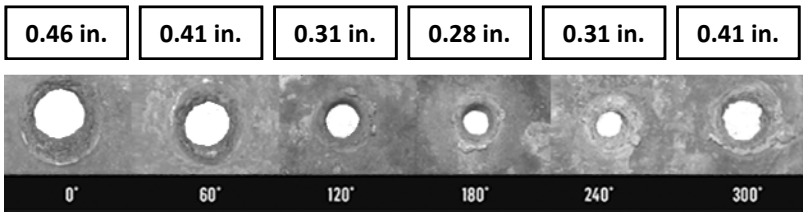
- Limited entry stimulation is a hydraulic fracturing technique in which the number of perforations available for fracturing fluids to enter the formation are "limited"
- Commonly used in multi-stage plug and perforate horizontal applications – wells will have many stages with each stage consisting of a number of clusters of perforations spaced at predetermined distances
- A higher pressure drop across the perforations (perforation friction) is desirable to encourage distribution of the stimulation treatment to all perforation clusters within the stage

CONVENTIONAL PERFORATING SYSTEMS

- *"It only matters that there are holes in the pipe!"*
- Entrance hole dia. (EHD)
  - Varies widely with clearance
  - Published data is averaged from API testing in lower grade and weight casing
- Penetration
  - Variation in clearance also has an impact on penetration



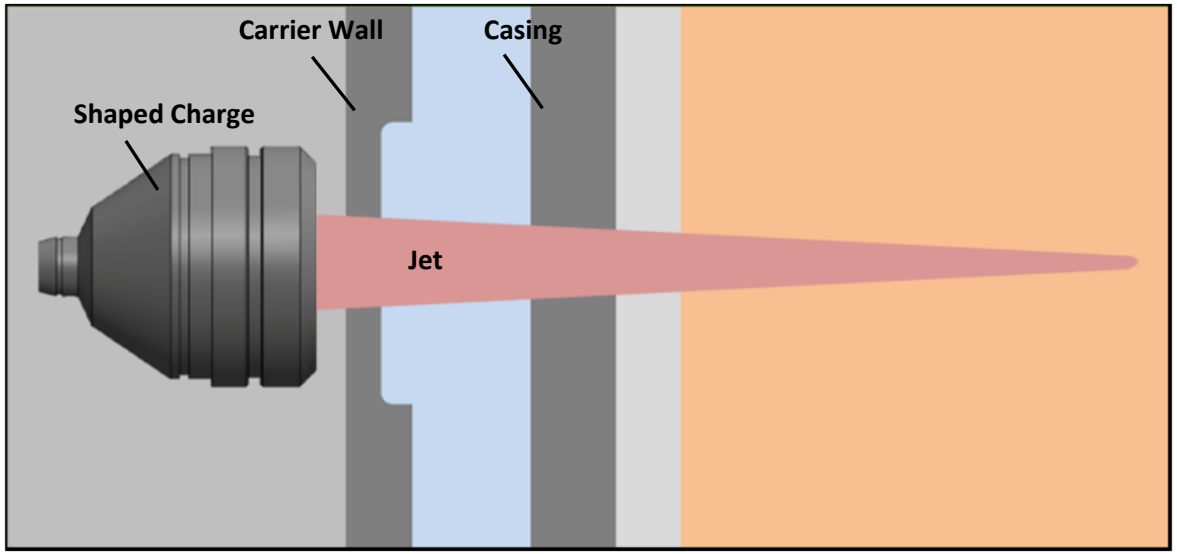
3-3/8 in. carrier in 5-1/2 in. 23lb/ft casing



Average EHD = 0.36 inches

CONVENTIONAL PERFORATING SYSTEMS

- The conventional shaped charge jet is designed to provide penetration
- Normally the diameter of the jet reduces at higher clearances - typically the high side hole migrates to a diameter of about 0.3 inches



EHD & LIMITED ENTRY STIMULATION

- The objective is to optimize the number of open perforations and perforation friction
- If the EHD varies circumferentially then radial distribution of the stimulation can be further compromised as perforation friction through each perforation will be different
- If the quoted average entrance hole is used then the cumulative pressure drop cannot be easily predicted

PERFORATION FRICTION

- Perforation friction calculation shows the importance of the EHD term (d_p)
- Small changes in EHD have a significant impact on perforation friction
- Accurate perforation diameter estimates are critical to the design of the stimulation
- Determining the number of perforations which are open and the corresponding pressure drop is difficult if EHD not consistent

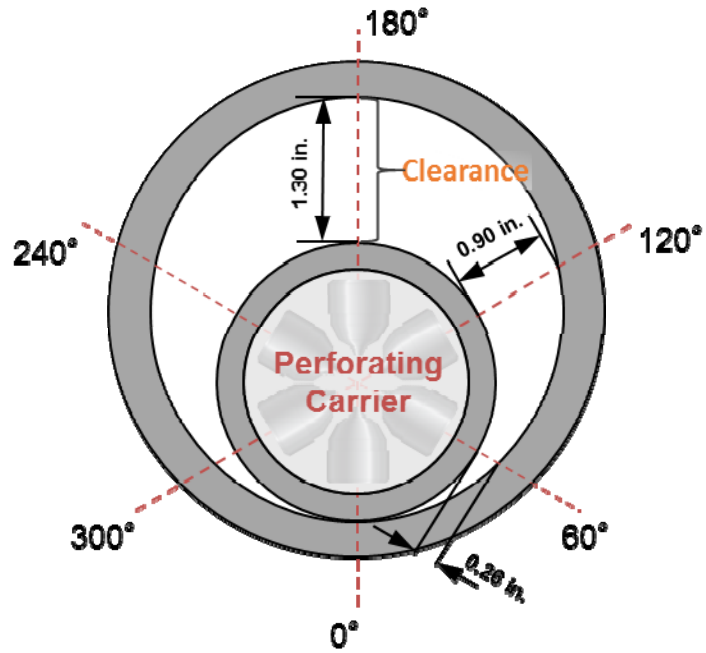
$$P_{pf} = \frac{1.975 q^2 \rho_f}{C_D^2 N_p^2 d_p^4}$$

Where:

P_{pf}	=	Perforation friction pressure (psi)
q	=	Total pump rate (bpm)
ρ_f	=	Slurry density (g/cm^3)
C_D	=	Perforation discharge coefficient
N_p	=	Number of open perforations
d_p	=	Perforation diameter (in)

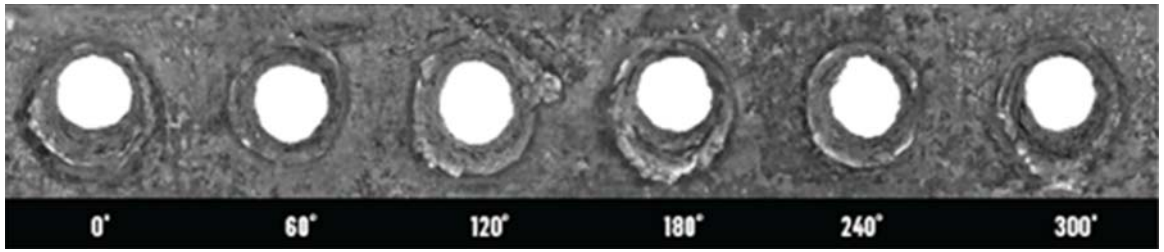
CONSISTENT PERFORATING SYSTEM

- Provides consistent entry hole diameter and penetration at all phases
- Consistent even though the clearance between the carrier and inner wall of the casing varies
- Options are available with 0.30 – 0.50 inch EHD



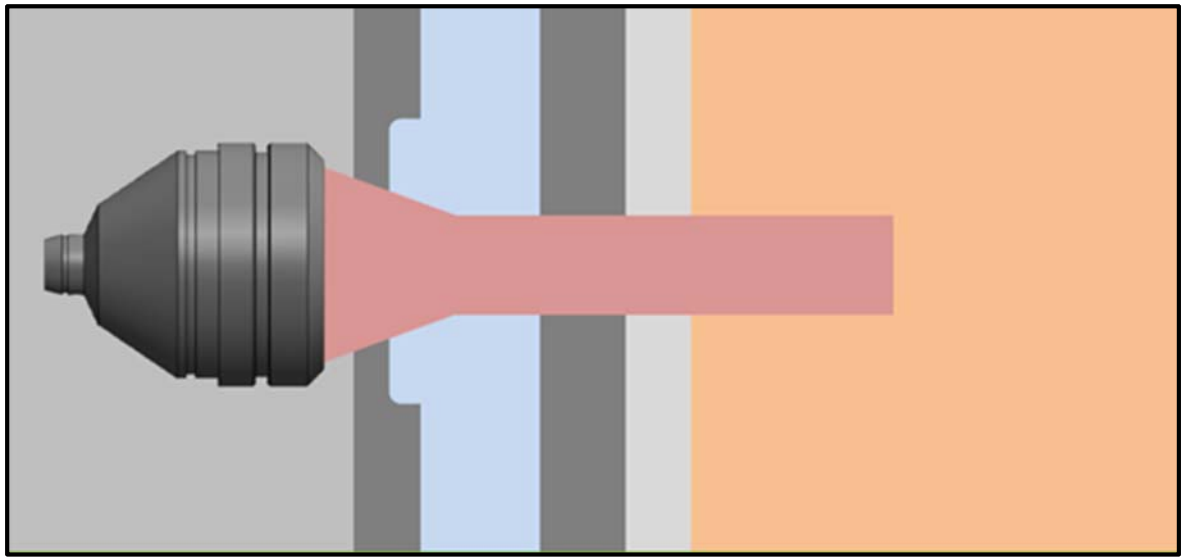
3-3/8 in. carrier in 5-1/2 in. 23lb/ft casing

0.40 in. – all phases/clearances



CONSISTENT PERFORATING SYSTEM

- Charges are uniquely designed and engineered to form a constant diameter fully developed jet
- The formation of the jet occurs in the charge case and near the inside wall of the gun carrier behind the scallop/spotface.
- The diameter of the jet in the initial (jet formation) region is larger than the diameter after it has been fully developed.

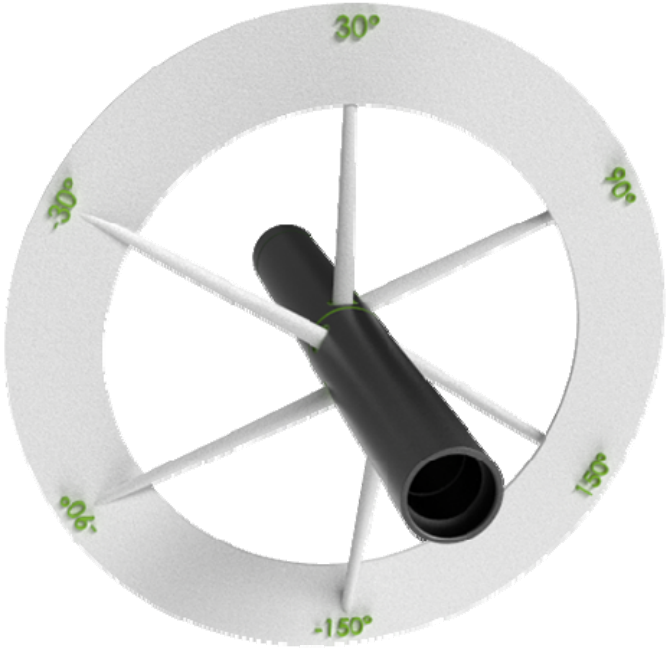


IMPACT OF CONSISTENT EHD

- Williston Basin – Bakken formation; ~10,000 ftTVD
- 4-1/2 in., 13.5 lb/ft, P-110 casing
- 43 perforated stages; number of clusters varied
- Step rate tests were conducted pre-acid, post-acid, and post-frac for each stage
- Post-acid data of 2-3/4 & 3-1/8 in. conventionally perforated stage showed perf. efficiency ranging from 44-70%
- 3-1/8 in. Consistent EHD system perforation efficiency <u>exceeded 80%</u>
- Near wellbore tortuosity was consistently low with each perforating system

RADIAL PLANE PERFORATING SYSTEMS

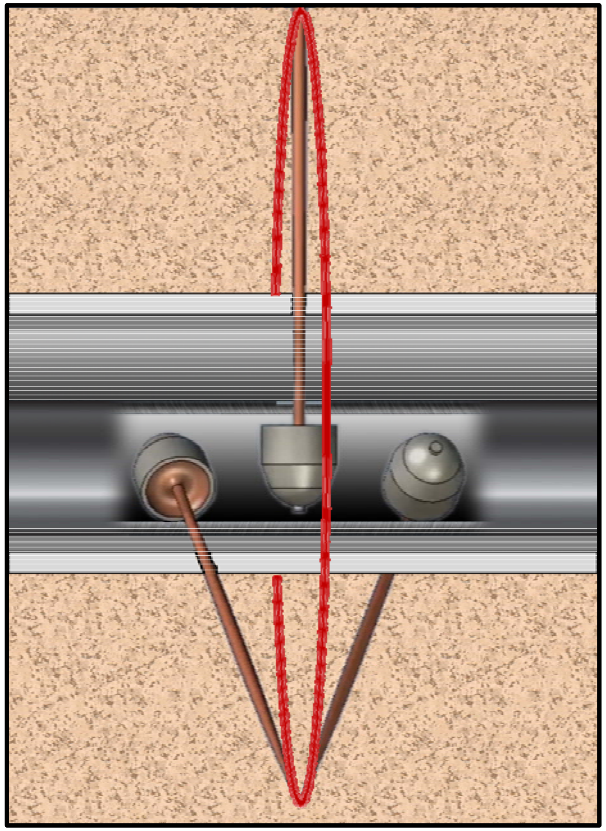
- Shaped charges are angled within the carrier to place fracture initiation on the same radial plane transverse to the wellbore orientation
- Uses reactive liner perforating technology to provide clear perforation tunnels, with fractured tips, improving connection to reservoir/formation



Patents: US7044225, US9038521, US9562421 and Patents Pending

RADIAL PLANE PERFORATING SYSTEMS

- Every perforation can feed fracture development since the fracture initiation points are on the same plane near wellbore
- Converging system allows strategic arrangement of tip fractures



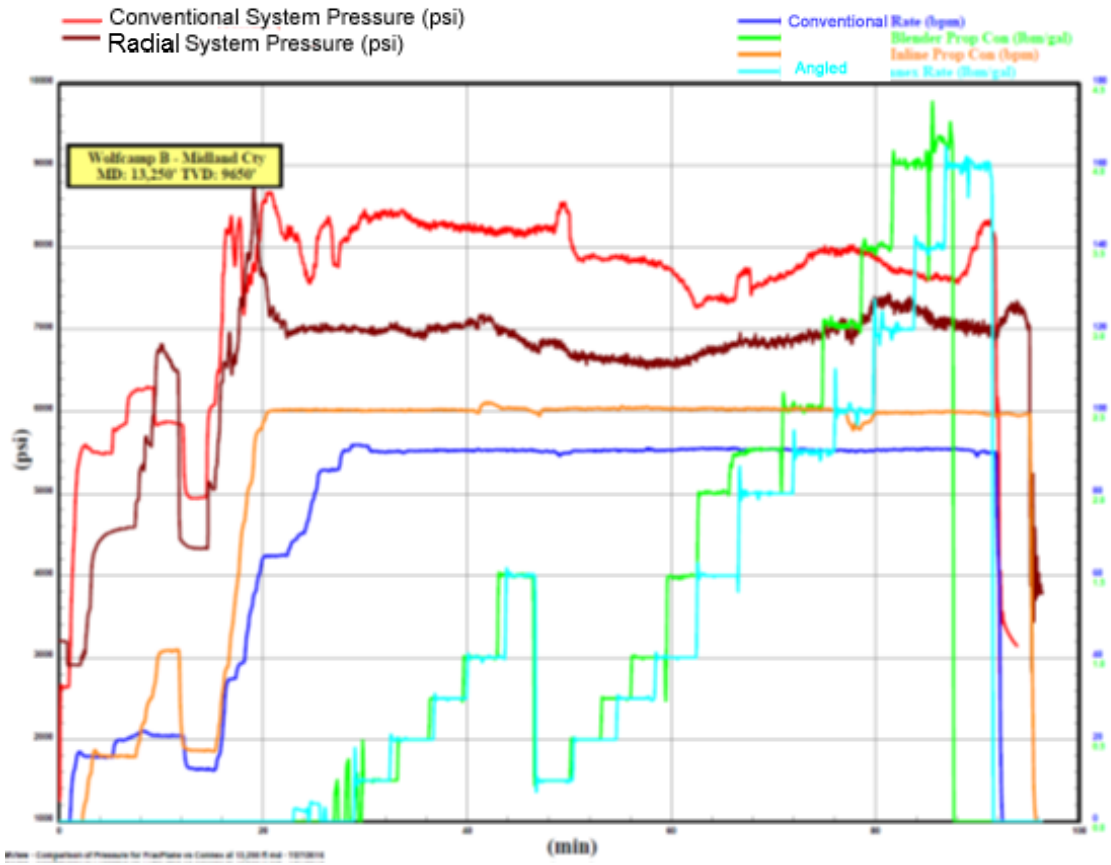
Patents: US7044225, US9038521, US9562421 and Patents Pending

REDUCED TREATING PRESSURE

Comparison of Conventional and Radial Plane systems

- Both wells perforated with the same reactive perforating charge (3-1/8 in. 22.7g reactive charge; 8 shots per cluster; 0.46 in. EHD)
- Wolfcamp B formation; Midland County, TX
- 5-1/2 in. 20 lb/ft P-110 casing at 9650 ftTVD

- Radial Plane treating pressure reduced approximately 1000 psi
- Increased pump rate from 90 bpm to 100 bpm at equivalent prop. concentration

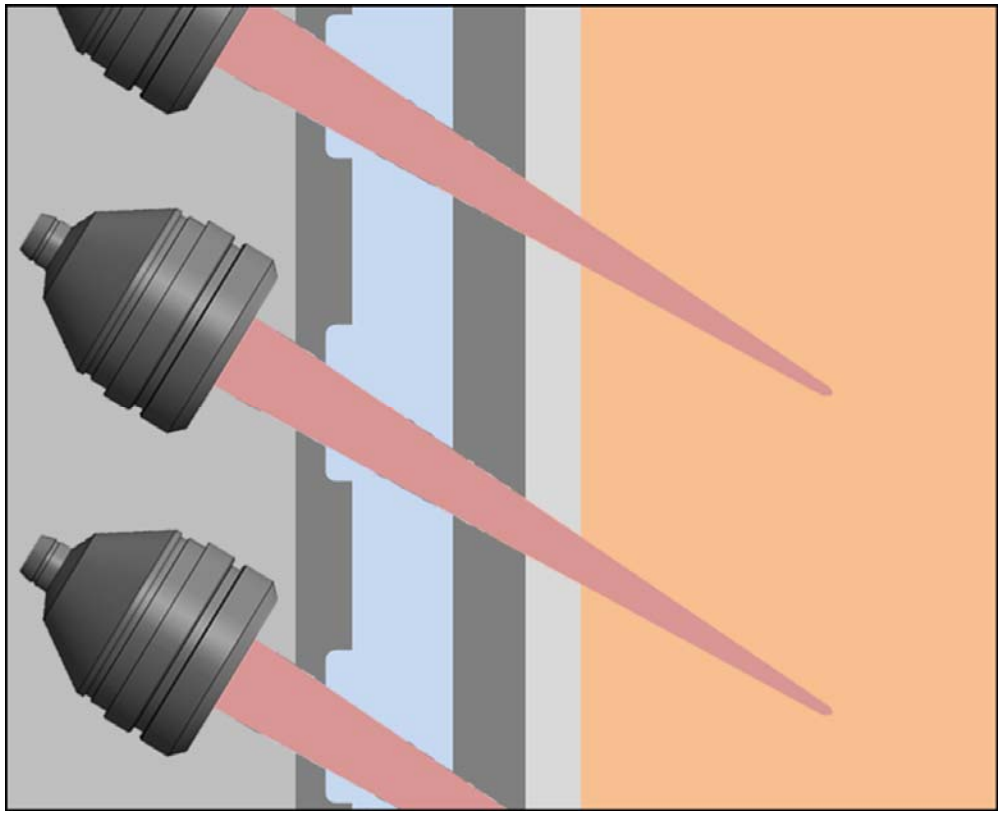


ANGLED PERFORATING SYSTEMS

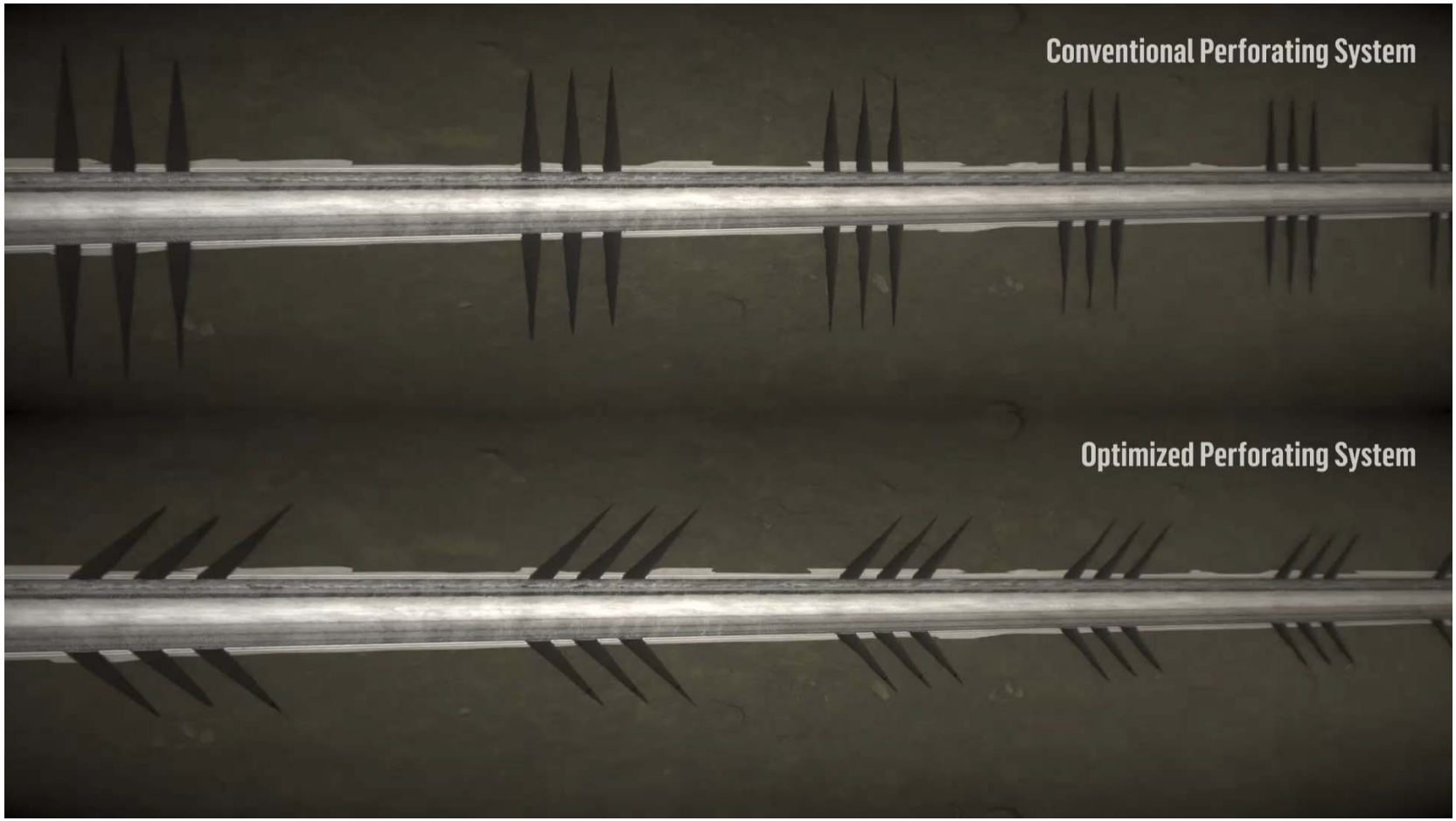
- Evolution of the system combines aspects of the Radial Plane and Consistent perforating systems
- Provides an “off ramp” for more efficient diversion of proppant
- Perforating tunnels are tilted in direction of fluid flow
- Constant entry hole size in eccentered conditions

Patents: US7044225, US9038521, US9562421 and Patents Pending

ANGLED PERFORATING SYSTEMS



- Angled holes are engineered to create a physical diversion on toe side of casing for proppant to naturally flow into the formation
- More uniform placement of proppant in all perf clusters within the stage

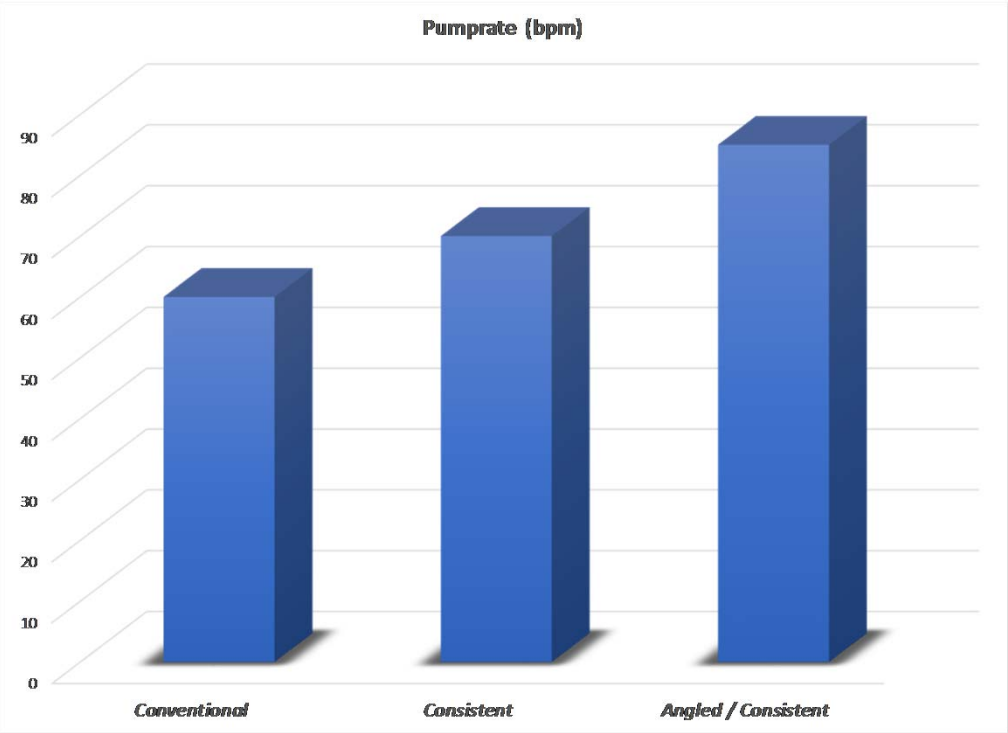

Conventional Perforating System
Optimized Perforating System

MEETING TARGET PUMP RATES

Comparing Conventional, Consistent, and Angled system

- Bakken well; 4-1/2 in., 13.5 lb/ft, P-110 casing; 10,500 ftTVD
- 31 stages completed at 2, 3, 5, 8, & 13 shots per cluster
- Target pump rate was 85 bpm

- Evaluation of 4 wells/system (total of 12)
- Using Conventional shaped charges only able to obtain a rate of 60 bpm
- Transitioned to a Consistent perforating charge and pump rate increased to 70 bpm
- Angled perforating system with Consistent perforating charges – obtain pump rates >85 bpm
- Operator now standardized to Angled/Consistent system for all future Three Forks and Bakken wells



CONCLUSIONS

- A consistent EHD perforation permits optimization of limited entry stimulations since all perforations have the same EHD and can equally contribute to the stimulation
- If proppant selection is based off the average perforation EHD then the holes which are smaller than this average diameter may actually screen out
- Consistent EHD charges provide higher perforation efficiency compared to conventional perforating charges run on the same well
- Radial plane perforating systems allow each perforation to feed fracture development since the fracture initiation points are on the same plane near wellbore – resulting in lower treating pressure and higher rates

CONCLUSIONS

- Angled perforating systems tilt the perforation tunnels in the direction of fluid flow allowing proppant to more naturally flow into the formation
- Able to maintain higher pump rates

NEXT SHALE 2017

Organized by: dmg::events

Navigating the Future of Unconventional Resources

UNIQUE LIMITED ENTRY CLUSTER PERFORATING SYSTEM IMPROVES FRACTURING EFFICIENCY IN HORIZONTAL WELLS

David Cuthill, GEODynamics, Inc.

GEODynamics®

NS17 - 042