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MENAPS 2016

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MUSCAT, OMAN

LIMITED ENTRY CLUSTER PERFORATING SYSTEM IMPROVES FRACTURING EFFICIENCY IN HORIZONTAL WELLS

MENAPS 2016-16

GEODynamics®
Engineered Perforating Solutions

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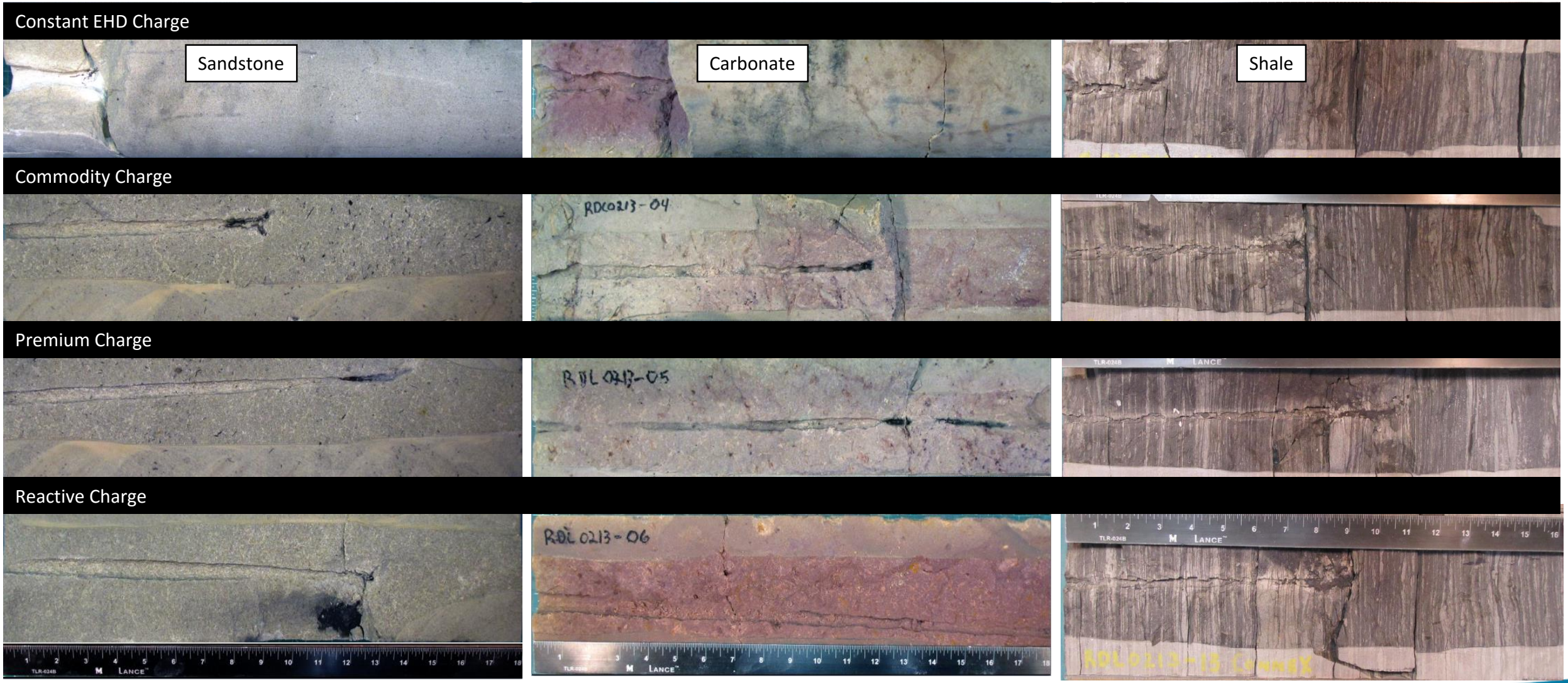
INTRODUCTION

- In conventional usage, well known vertical well perforating tools have been successfully adapted to horizontal wireline plug and perforation applications
  - Initially limited entry meant 4 shot clusters
  - Wells were 4 – 12 stages
  - Cluster spacing was greater than 500 ft apart
  - Wells were completed with TCP at the toe

- New learnings have pushed operators to new techniques
  - (2-3) shot, 6 shot, or 12 shot clusters predominatly
  - Wells are 20-40 stages
  - Cluster spacing is 250 ft or less
  - Valves at the toe stage dramatically lower cost

- Why? And does this mean something for perforating tools?

NEW TOOLS FOR NEW TECHNIQUES - CHARGES



SYSTEM DESIGN FOR HORIZONTAL UNCONVENTIONAL WELLS

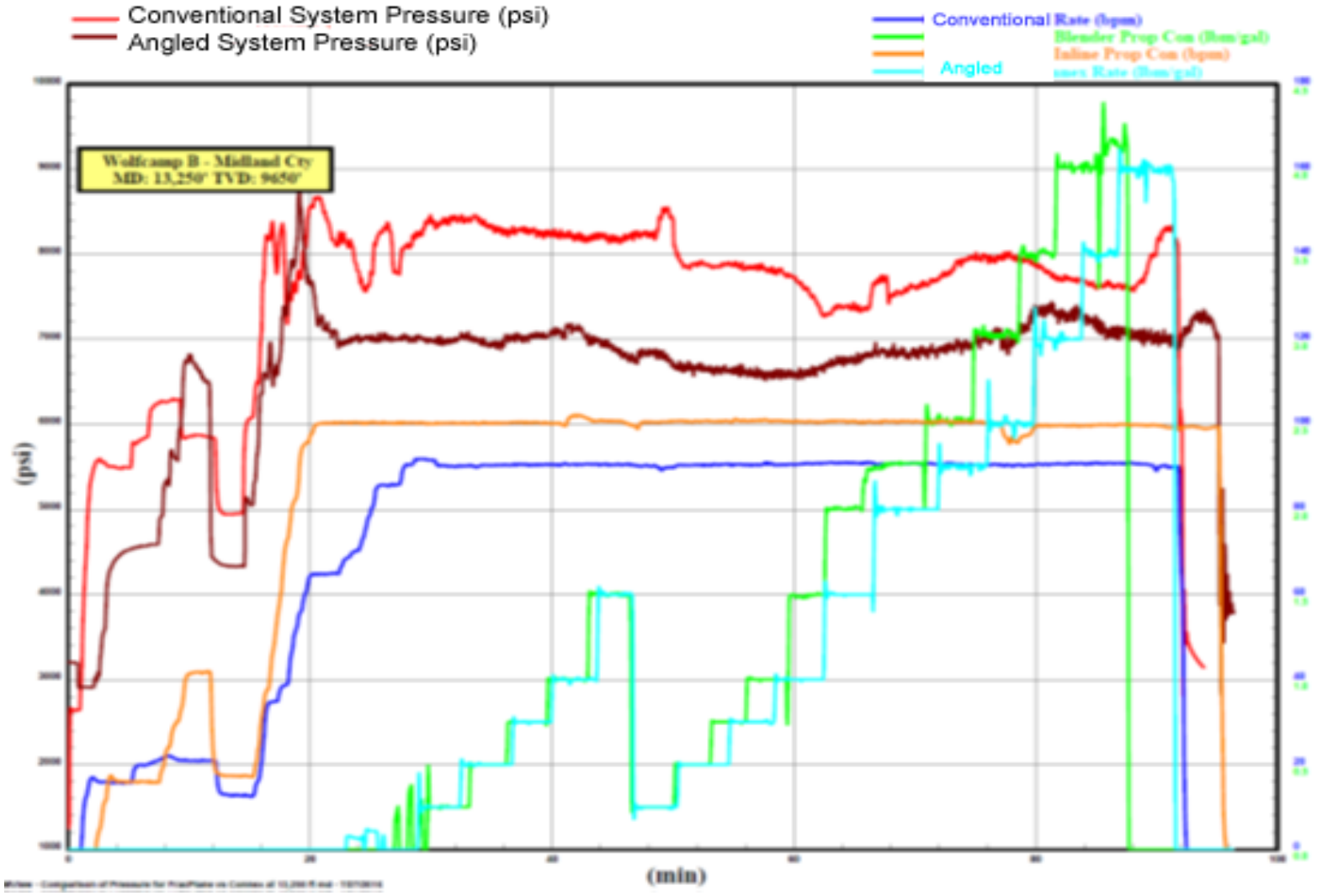
- Do Only the Holes Matter?

- Industry Standards Through Trial and Error: Why?
  - 6 Shot per Foot (SPF) Clusters in US Unconventional
  - Alternate: Multiple clusters at 180 degrees (not oriented!)

- Operators are finding the exceptions in Well Design!

EXAMPLE 1 – REDUCED TREATING PRESSURE

- Comparison between conventional and new cluster perforation system
- Both wells perforated with the same reactive perforating charge
- Wolfcamp B formation; Midland County, TX
- TVD 9650 ft
- Treating pressure reduced on average approximately 1000 psi – at increased pump rates



EXAMPLE 2

- Number of horizontal wells in the same pad perforated with both conventional and cluster based perforating systems
- RELIABLY IMPROVED PERF FRICTION without ACID

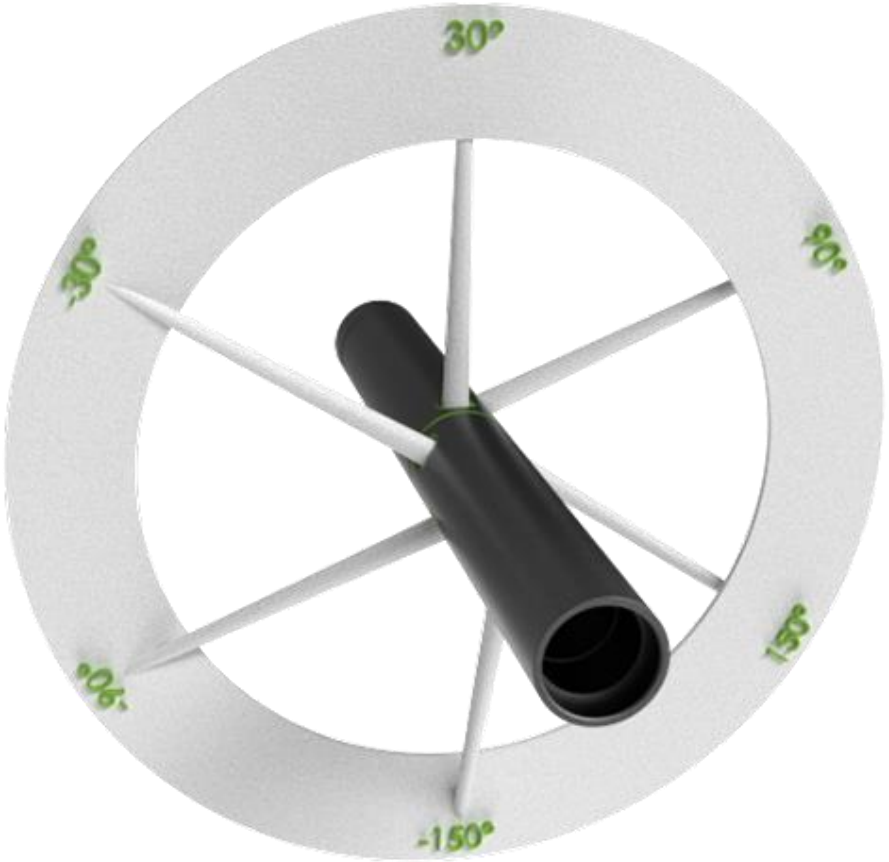
Well Name	Charge Type	Avg Treating Pressure	Avg Treating Rate	Avg Max Rate	Avg Hyd HP	Acid Volume / Well	Avg FR Volume	Avg Gel Volume	Calc'd Perf Friction	Avg Stage Pump Time
	Conventional	8278	95.5	100.8	20452	192	162	580	938	1:56
	Conventional	8155	95.5	99.9	19968	45	173	568	746	2:00
	Conventional	8544	86.3	94.4	19768	0	221	607	1328	2:12
	Conventional	7999	98	100.4	19684	88	140	486	1220	1:47
	Conventional	8271	97.4	100	20272	98	149	463	1265	1:48
	Conventional	8598	96.5	99.7	21010	42	140	531	1178	1:46
	Conventional	7955	98.4	100.8	19654	186	142	569	1293	1:55
Average		8257	95	99	20115	93	161	543	1138	1:54
	Angled	7858	98.6	101	19452	0	150	550	1084	1:49
	Angled	7881	98.7	100.6	19432	0	135	542	1109	1:50
	Angled	7926	99.1	100.7	19562	0	136	546	749	1:47
Average		7888	99	101	19482	0	140	546	981	1:48
Delta		369	-3	-1	633	93	21	-3	158	0:06
% change		-4%	4%	1%	-3%	-100%	-13%	0.50%	-14%	-5%
$ Value		-	-	-	$ 9,419.00	$ 11,718.00	$ 629.92	$ (84.55)		
Per stage Savings					$ 495.72	$ 616.74	$ 33.15	$ (4.45)		

NEW DESIGN ELEMENTS FOR PERFORATING SYSTEMS

- Each gun is designed for an individual cluster
- The arrangement of charges is tuned so that
  - An additional charge in a cluster provides maximum benefit
  - A subtracted charge in a cluster yields minimum loss
- Systems are not constant phase or shot density, but target probability of placement with a given number of shots in a cluster
- For example: 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, and 14 shot designs.
- Where lower number of shots are desired, orientation may be used, which impacts system design

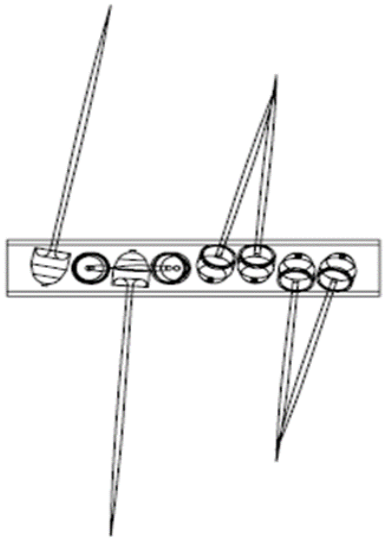
NEW PERFORATING SYSTEM

- Uses angled perforations arranged in banks to place fracture initiation points on the same plane near wellbore
- By connecting transversely to the fracture planes, every hole feeds the fracture, and variations due to hole size are minimized
- Shot configurations available: 2, 3, 4, 5, 6, 7, 8, 10, 12, and 14 shot designs
- This system is optimized to be run without orientation

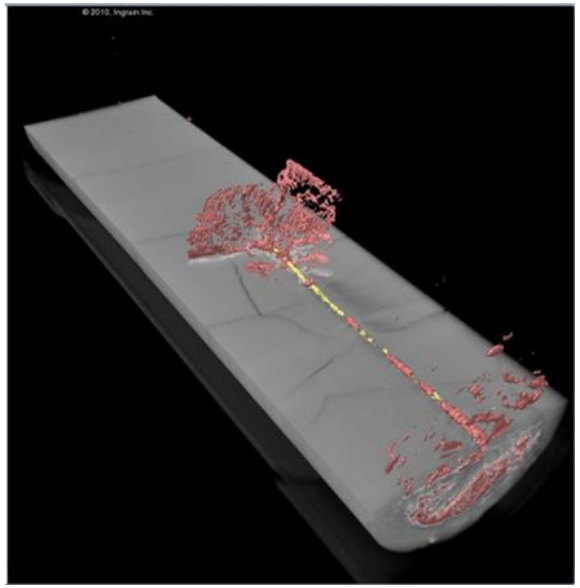


NEW PERFORATING SYSTEM

- For Formation Reach, Carbonates, Difficult to Break Formations, and Operational Advantage :



Guns



Reactive Liner Charges

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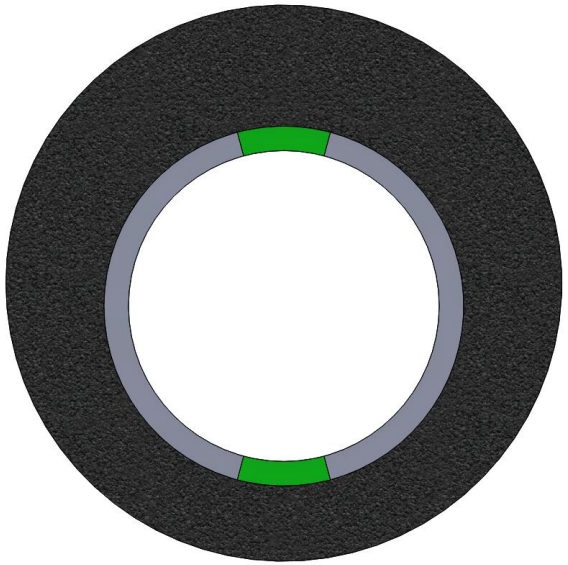
DOMINANT HOLES

- Operators Report: Downhole cameras have shown a single dominant hole in many clusters
- The dominant hole is obvious due to preferential erosion of that hole vs. the remaining holes.
- The eroded hole is often more 2-3 times the original diameter

DOMINANT HOLE DISTRIBUTION AND WELLBORE STRESS

30 Degree Arc
Lowest Stress
Smallest Hole

2X 150 Degree Arcs
High Stress
Hole Varies

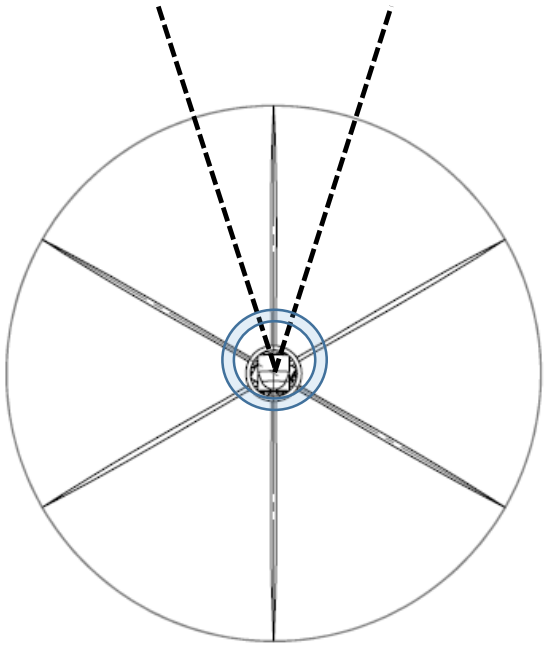


30 Degree Arc
Low Stress
Largest Hole

- With Conventional Phasing, dominant holes are distributed statistically:
  - Downward 30 deg arc: 70%
  - Upward 30 deg arc: 20%
  - Either remaining side: 10%

- Conceptually, this can be accounted for due to stress distribution around the casing and the variation in hole sizes.

DOMINANT HOLES: PHASING AND PLACEMENT

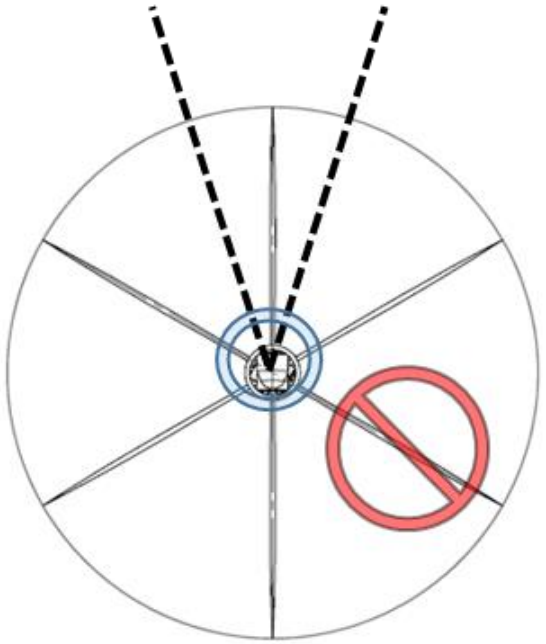


- For a 6 shot, 6 SPF, 60 deg Gun, the chance of placing a perforation hole in the preferred stress arc of the wellbore (up or down) is

50%

- The fully loaded 6 shot 60 deg cluster has the highest chance of any conventional fixed phase, fixed density system, which may explain the popularity of this system.

DOMINANT HOLES: DOWNLOADING

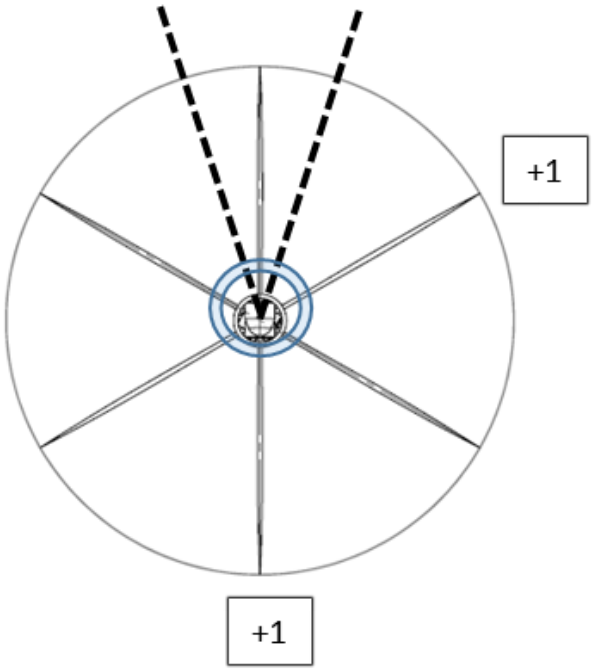


- The breakdown pressure of each cluster will vary with this statistic, like the flip of a coin: high or low.
- Downloading the 6 shot gun to 5 shots will affect the statistical chance of placing a shot appropriately, and increase the chance of variation from cluster to cluster.

68%

- It doesn’t matter how you download.

DOMINANT HOLES: UPLOADING



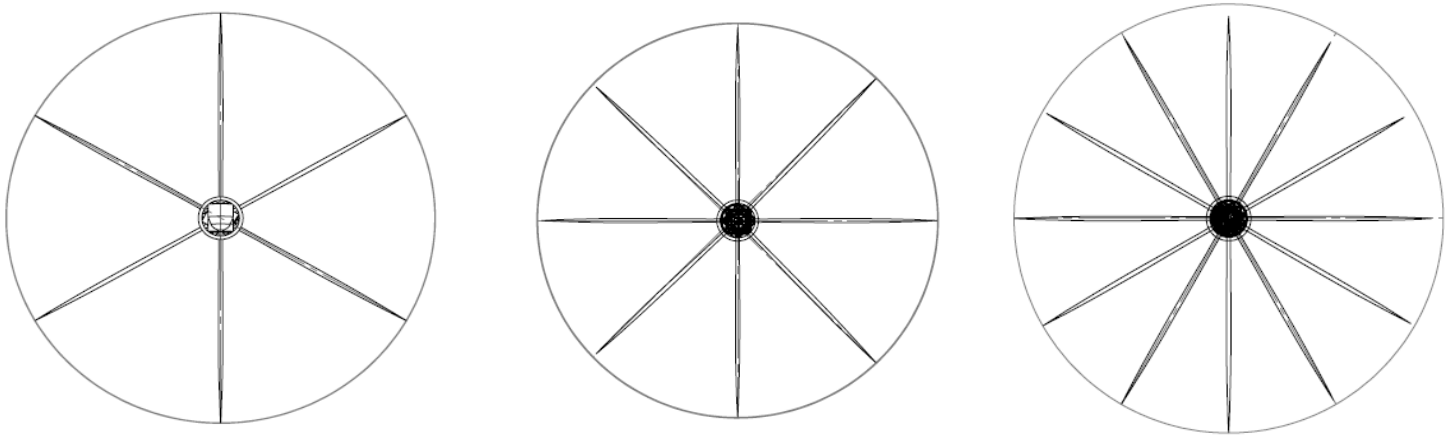
- Adding a shot to a constant phase system will not improve the chances.
- The seventh shot has a 16% chance to be in the top or bottom arc of interest.

50%

- It doesn't matter how you upload.
- The additional shot may further unbalance the clusters, if it moves more dominant holes to the low side.

CLUSTER BASED PERFORATING SYSTEMS

- Converging System and Non Converging System Available
- Designed to be run without orientation
- Phasing to improve perforation placement



6 Shot
U=50%

8 Shot
U=33%

12 Shot
U=0%

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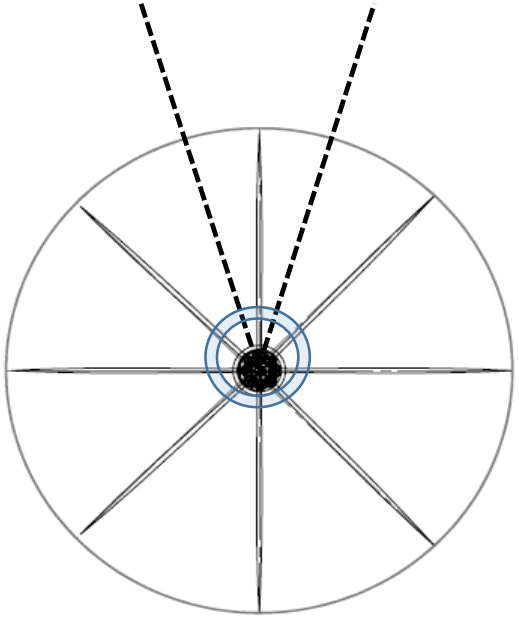
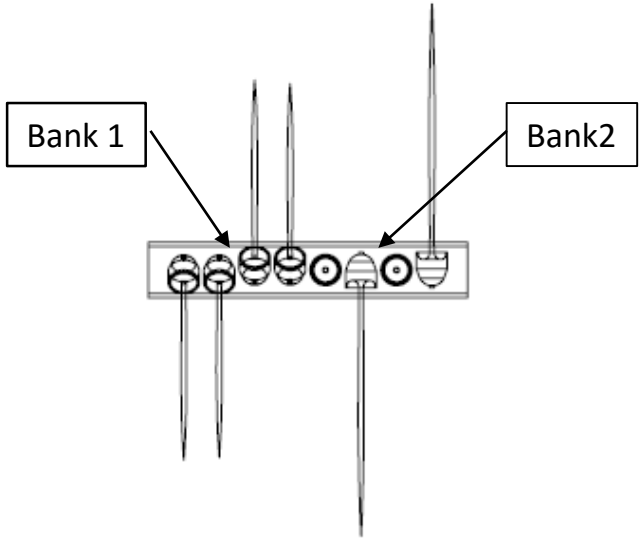
CLUSTER BASED PERFORATING SYSTEMS

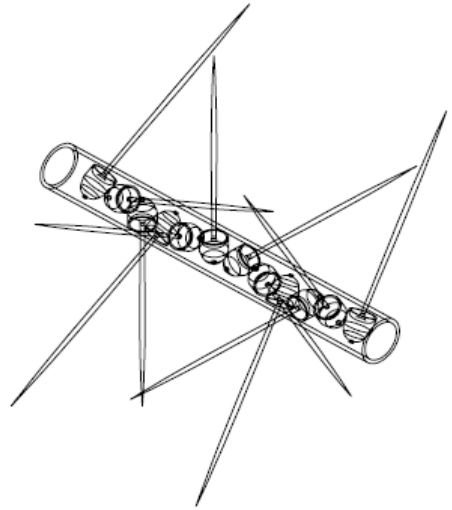
- Dual bank design groups opposing charges for best planar performance
- Converging charges offset hole size variation (Every perforation feeds a planar frac)
- Converging system allows strategic arrangement of tip fractures



8 Shot
End



8 Shot
Side



8 Shot 3D

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PERFORATION SYSTEMS FOR CLUSTERS

- Application:
  - Limited Entry Perforating Systems
- Benefits:
  - Arranges perforations for statistical placement
  - Available in 2,3,4,5,6,7,8,9,10,12, or 14 shot per cluster configurations, in 3-1/8” Guns
- Opportunities to treat more clusters:
  - Enables Advanced Limited Entry Frac Design
  - Balance injection between clusters through stage design with new tools
  - Break down troublesome wells
  - Achieve higher rates at lower pressures
  - Reduce pumping cycle time

NEW TOOLS ENABLE NEW TECHNIQUES FOR WELL COMPLETION

- Cluster based perforation guns combined with charge options can enable
  - Extended reach into the well
  - Arrangement of initiation points
  - Rescue for difficult to break down formations

- Effective holes improve reliability and repeatability
- Mix hole sizes in a single stage
- Mix shaped charge family types in a single stage
- Change design as you work up the well – (Charge – Gun – Cluster)
- Mix charge and system types in a single cluster with orientation

- Also – in conjunction with precision hole size systems: Advantageous Cement Squeeze

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Well Design will Never be the Same

MENAPS 16-08

IMPROVED HYDRAULIC FRACTURING PERFORATION EFFICIENCY OBSERVED WITH CONSTANT ENTRY HOLE AND CONSTANT PENETRATION PERFORATING SYSTEM