Optimizing Perforating Charge Design for Stimulation

HALLIBURTON

Fracturing Unconventional Reservoirs

- Deep Penetrating (DP) Charges
  - Natural Completions
  - Focused on depth of Penetration
  - Hole size is usually an after thought

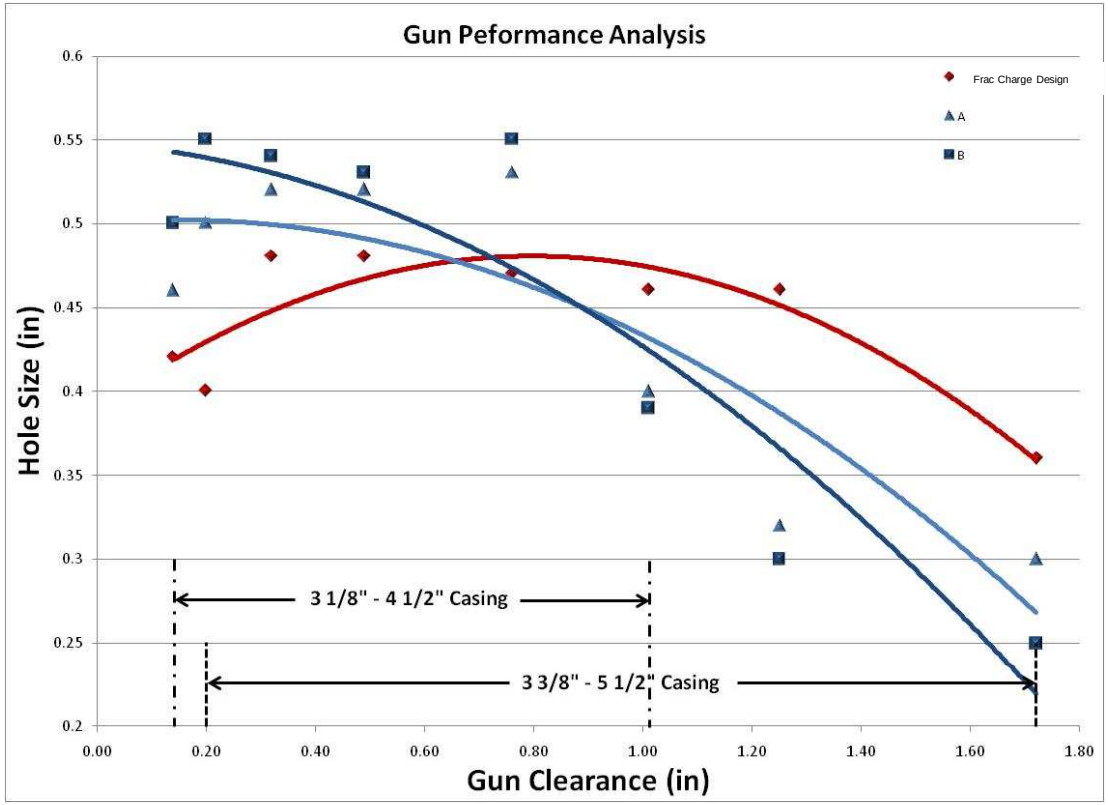
- New Design FRAC Charge
  - Stimulated Completions
  - Focused on Hole Size and Consistency

Optimal FRAC Gun

- 6 spf 60
- 3 1/8” gun in 4 ½” casing with a 0.48” avg. casing hole
- 3 3/8” gun in 5 ½” casing with a 0.42” avg. casing hole
- Depth of penetration is not important
- Hole size consistency without centralization

What is more important

- Hole size
- Hole size consistency

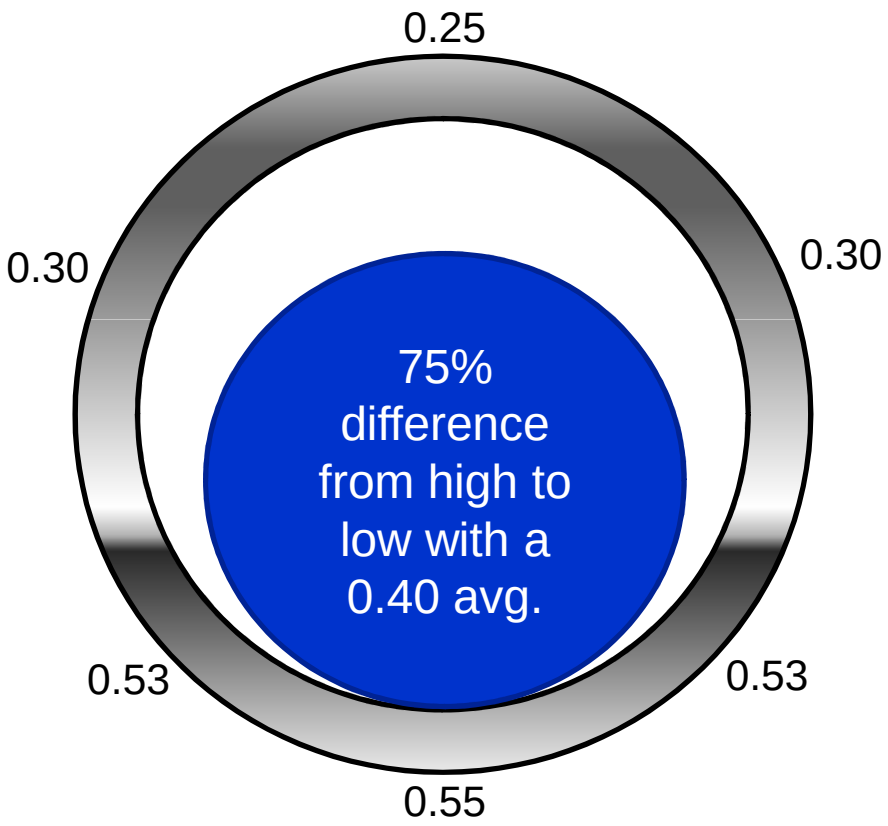


3 1/8"				
Shot Phase Angle	Clearance	Average		
		A (21g)	B (19g)	Frac Charge Design (21g)
0	0.14	0.46	0.50	0.42
60/300	0.32	0.52	0.54	0.48
120/240	0.76	0.53	0.55	0.47
180	1.01	0.40	0.39	0.46
Total Average		0.49	0.50	0.46
(AMax-AMin)/Ave		26.8%	31.8%	13.0%

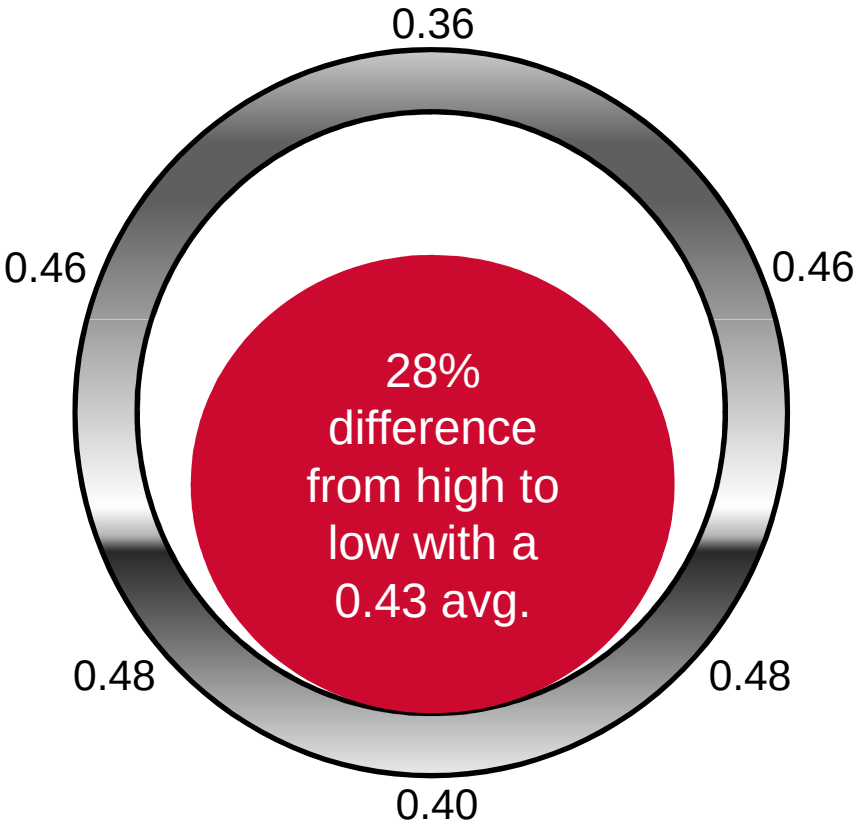
3 3/8"				
Shot Phase Angle	Clearance	Average		
		A (21g)	B (19g)	Frac Charge Design (21g)
0	0.2	0.50	0.55	0.40
60/300	0.49	0.52	0.53	0.48
120/240	1.25	0.32	0.30	0.46
180	1.72	0.30	0.25	0.36
Total Average		0.42	0.40	0.43
(AMax-AMin)/Ave		52.4%	75.0%	27.9%

Consistent Hole Size Without Centralization

3 3/8” gun in 5 ½” casing



Industry Charge B



Frac Charge Design

21 gram Frac Charge Design Gun System

- 21 grams RDX
  - 3 1/8” 6 spf 60
    - 0.46” hole in 4 ½” casing
    - 13% variance*
  - 3 3/8” 6 spf 60
    - 0.43” hole in 5 ½” casing
    - 28% variance*

*(Ave. Max Hole - Ave. Min Hole) / Ave Hole

FEA Modeling

- Abaqus™ is a software application for finite element analysis (FEA) and computer-aided engineering
  - Calculate stress distribution along the perforation tunnels and the wellbore
  - Established a correlation between the breakdown pressure and the entrance hole diameter of perforation tunnel

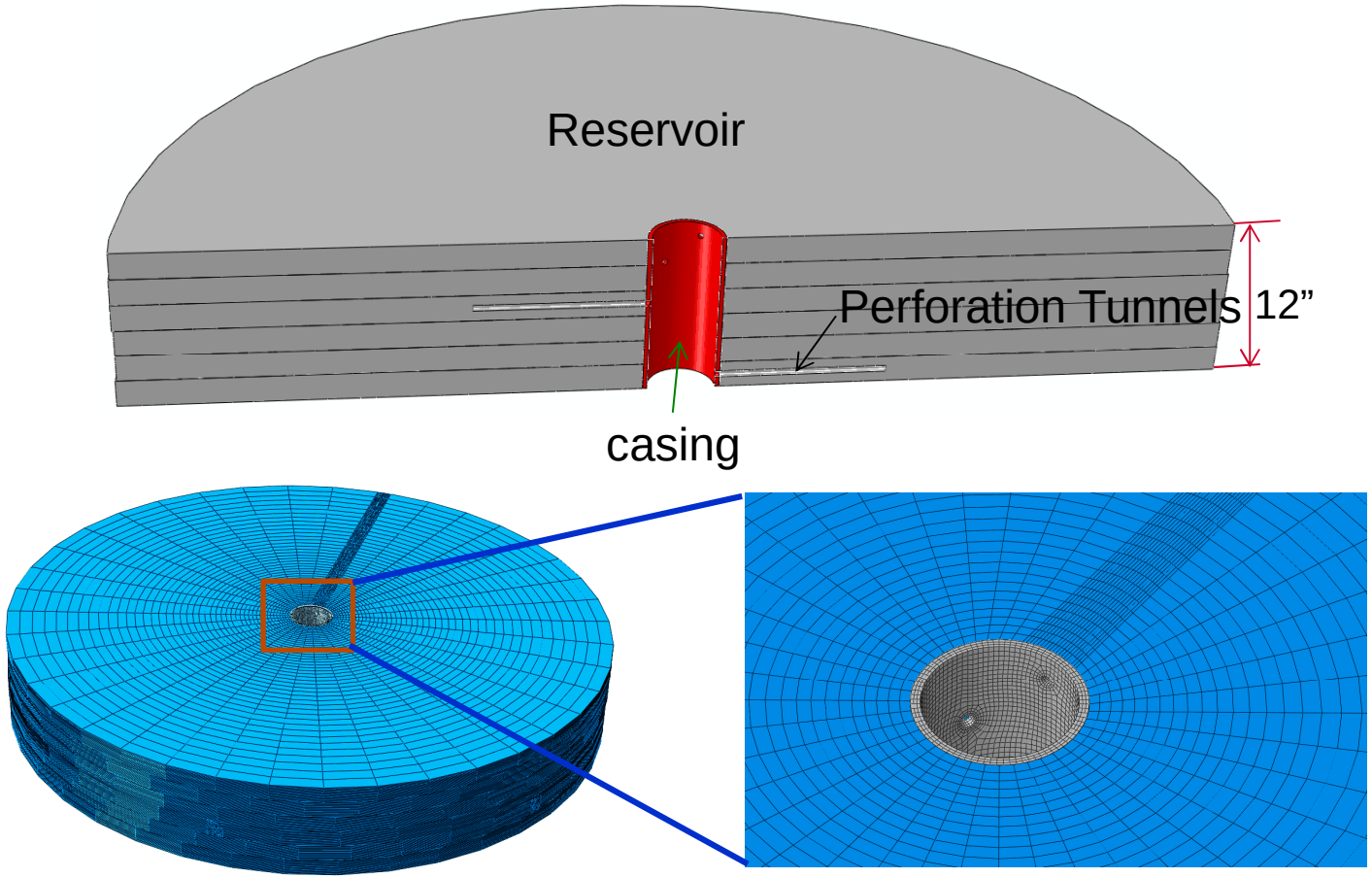
3 3/8” Gun in 5 ½” Casing Scenario

3 3/8“ Gun System				
Shot Phase Angle	Clearance	Average		
		Ideal Case	Industry Charge (19g)	Frac Charge Design (21g)
0	0.2	0.43	0.55	0.40
60/300	0.49	0.43	0.53	0.48
120/240	1.25	0.43	0.30	0.46
180	1.72	0.43	0.25	0.36
Total Average		0.43	0.40	0.43
(AMax-AMin)/Ave		0%	75.0%	27.9%

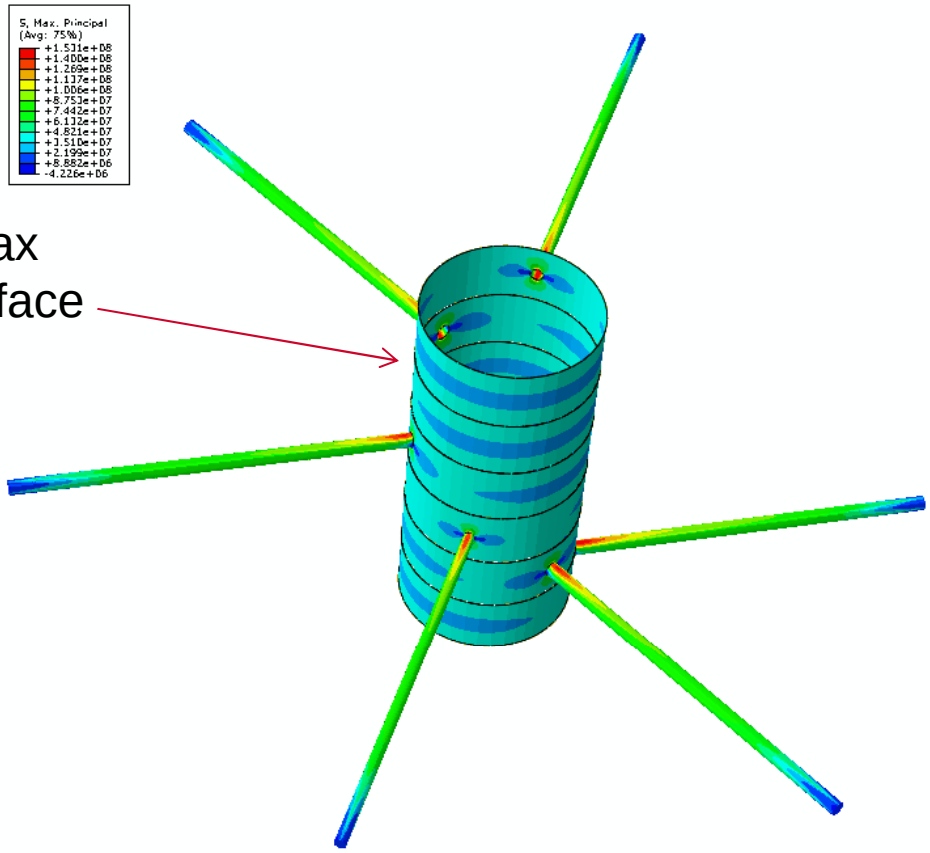
Full-scale model, six perforating tunnels, 12” height of reservoir, 5.5” wellbore diameter, 0.304” casing wall thickness.

FE Mesh Configuration

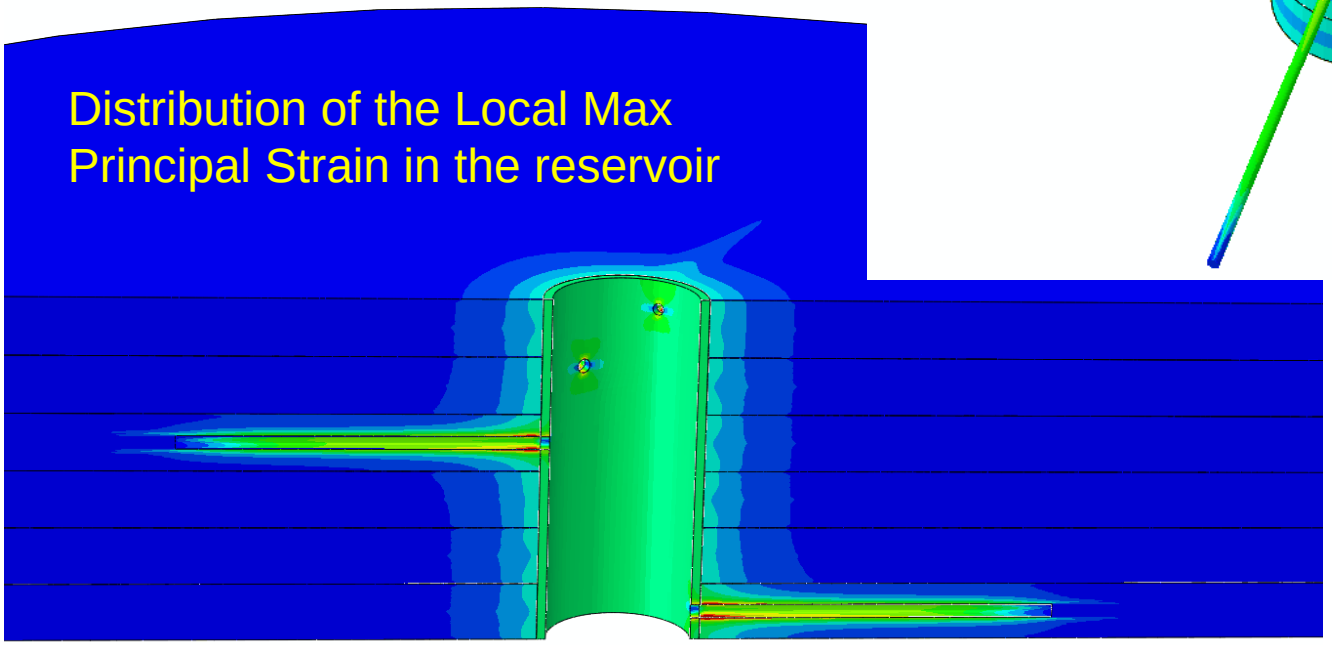
Uniform pressure (=100MPa) is applied to the surface of the casing and the perforation tunnels.



Numerical Results

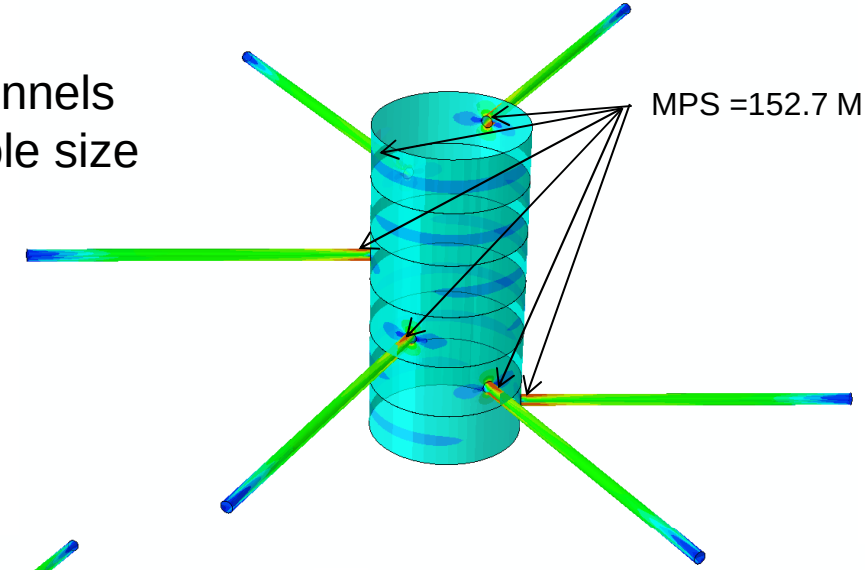


Distribution of the Local Max Principal Stress on the surface of perforation tunnels

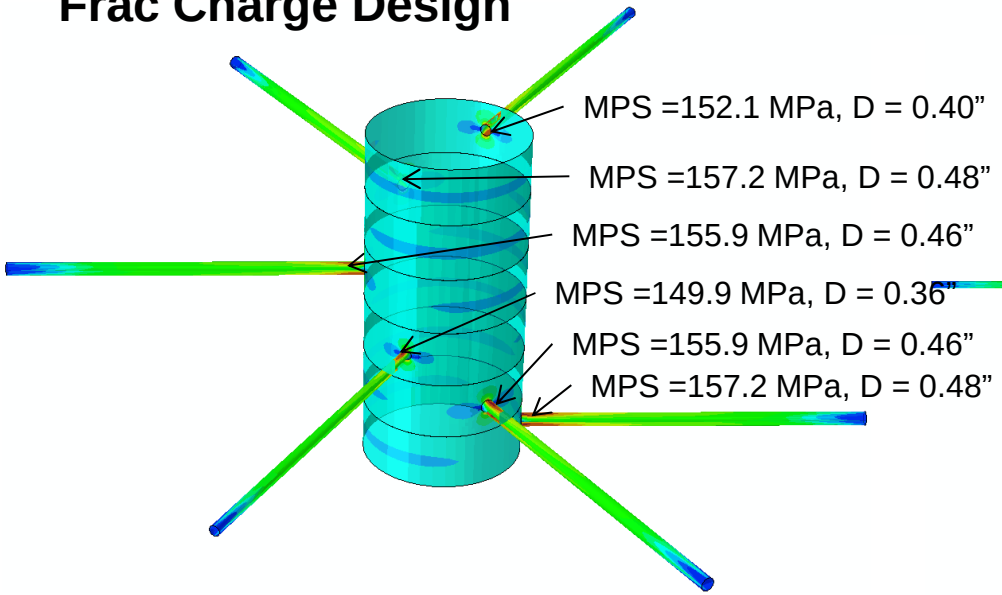


Numerical Results

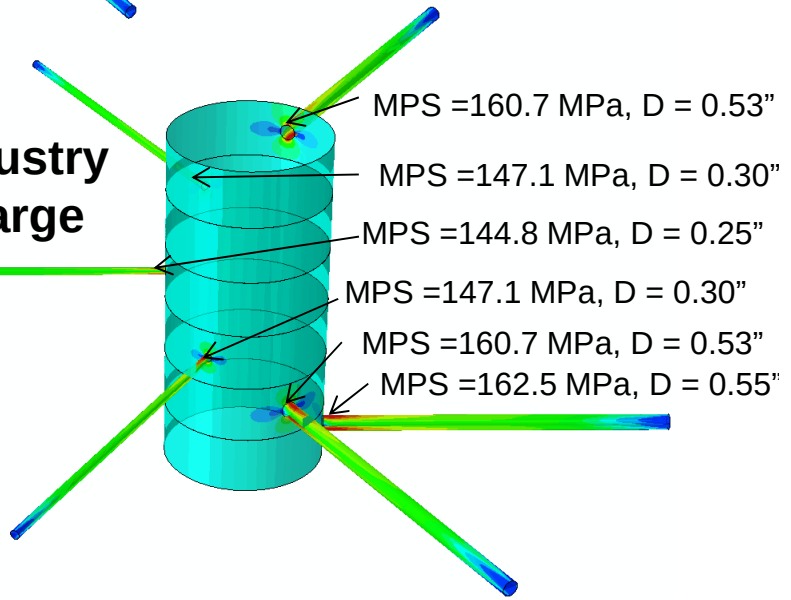
Ideal Case: six tunnels have the same hole size



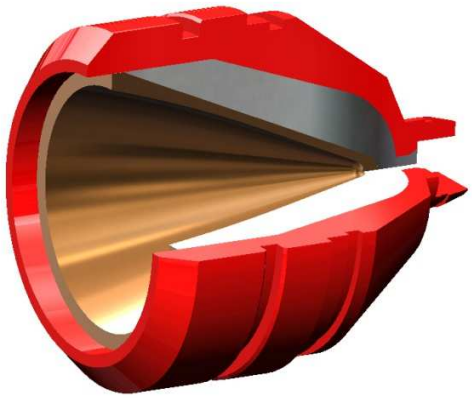
Frac Charge Design



Industry Charge



FEA Conclusions



3 3/8“ Gun Systems				
System	Rotation	Clearance (in)	Hole Diameter (in)	Max Principal Stress (MPa)
Ideal Case	0	0.2	0.43	153.9
	60/300	0.49	0.43	153.9
	120/240	1.25	0.43	153.9
	180	1.72	0.43	153.9
Frac Charge Design	0	0.2	0.40	152.1
	60/300	0.49	0.48	157.2
	120/240	1.25	0.46	155.9
	180	1.72	0.36	149.9
Industry Charge	0	0.2	0.55	162.5
	60/300	0.49	0.53	160.7
	120/240	1.25	0.30	147.1
	180	1.72	0.25	144.8

- Breakdown pressure will increase as the perforation tunnel diameter decreases
- The Frac Charge Design provides less variation in the breakdown pressures thus improves pressure distribution to ensure even treatment of perforations
  - Increase stimulation efficiency

Case History
Field Trial 1 – Permian Basin

21 gram Frac Charge Design Field Trial #1

- Subject test well in Martin County, Texas
  - Stage #1 Perforated August 2011
    - Atoka Formation – 6 Clusters with 49 holes total
    - Formation characteristics:
      - Medium hard Limestone inter-bedded with soft to medium hard siltstone and shale.
    - History in this formation:
      - Difficult to breakdown and obtain injection rate
      - Difficulty is attributed to the wide variation in formation hardness
  - Stage #2 Perforated August 2011
    - Strawn Formation – 5 Clusters with 44 holes total
    - Formation characteristics:
      - Medium hard Limestone inter-bedded with medium hard shale.
    - History in this formation:
      - Difficult to breakdown, injection rates obtainable

21 gram Frac Charge Design Field Trial #1

- Benchmark well was also in Martin County, Texas
  - Located 9 miles to the Southwest of test well
  - By log correlation is correlative to test well
  - Perforated with Commercial ‘Good Hole’
  - Stage #1 Perforations
    - Atoka Formation – 6 Clusters with 49 holes total
  - Stage #2 Perforations
    - Strawn Formation – 6 Clusters with 50 holes total

Stage #1 Results and Observations

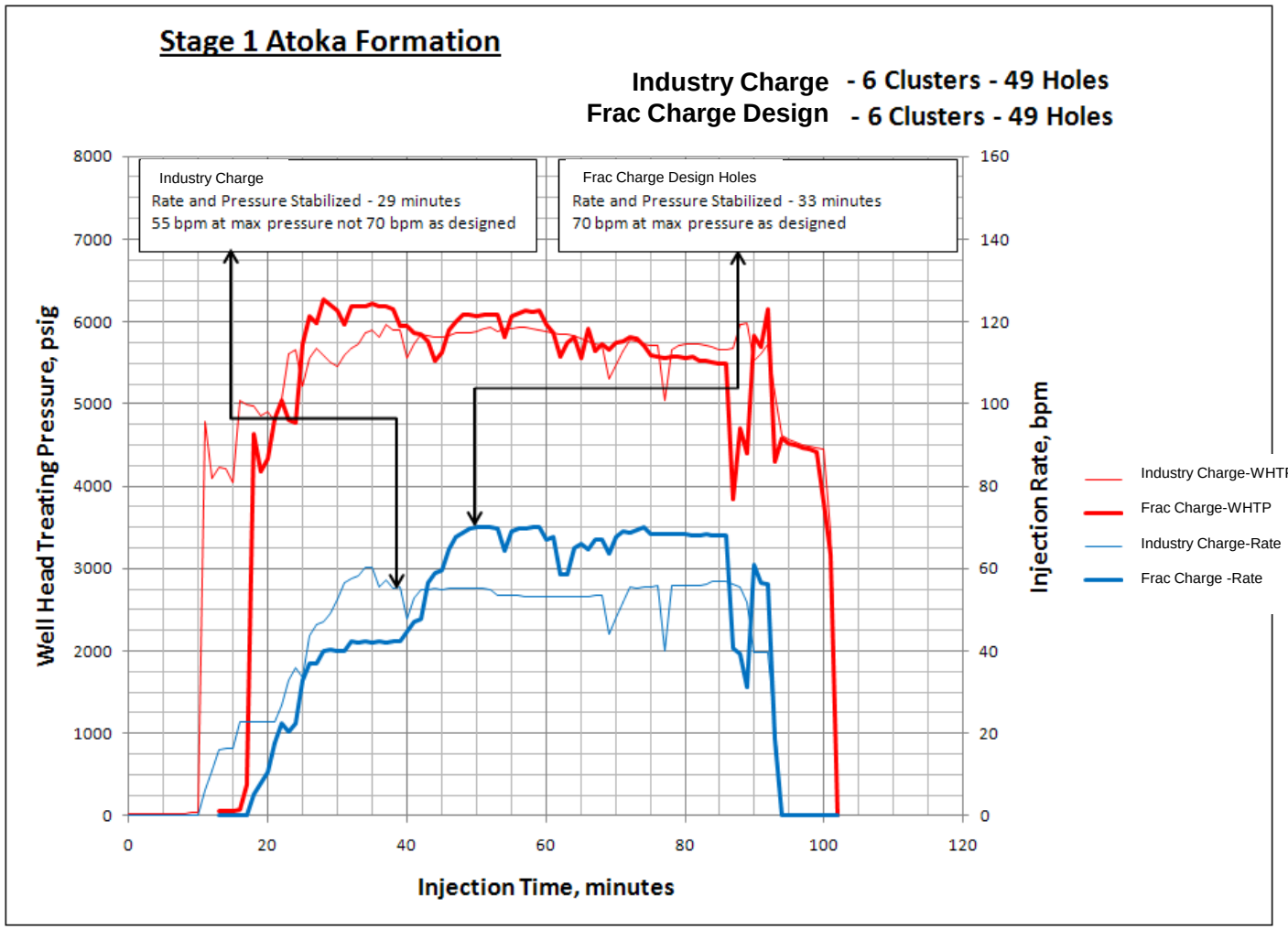
- Comparison of Rate and Pressure Response
  - Test Well reached designed rate (70 bpm) and pressure in 33 minutes
    - Charges were loaded in a low pressure carrier therefore the bottom cluster was not pumped into prior to the treatment as recommended
  - Benchmark well reached a stabilized rate and pressure in 29 minutes. The final rate was 55 bpm, 15 bpm less than designed.

- The 21 gram Frac Charge perforations resulted in an increase of 15 bpm at the same treating pressures

Stage #1 Rate and Pressure Overlay

21 gram Frac Charge Design Field Trial #1

August 2011 Martin County, Texas



Stage #2 Results and Observations

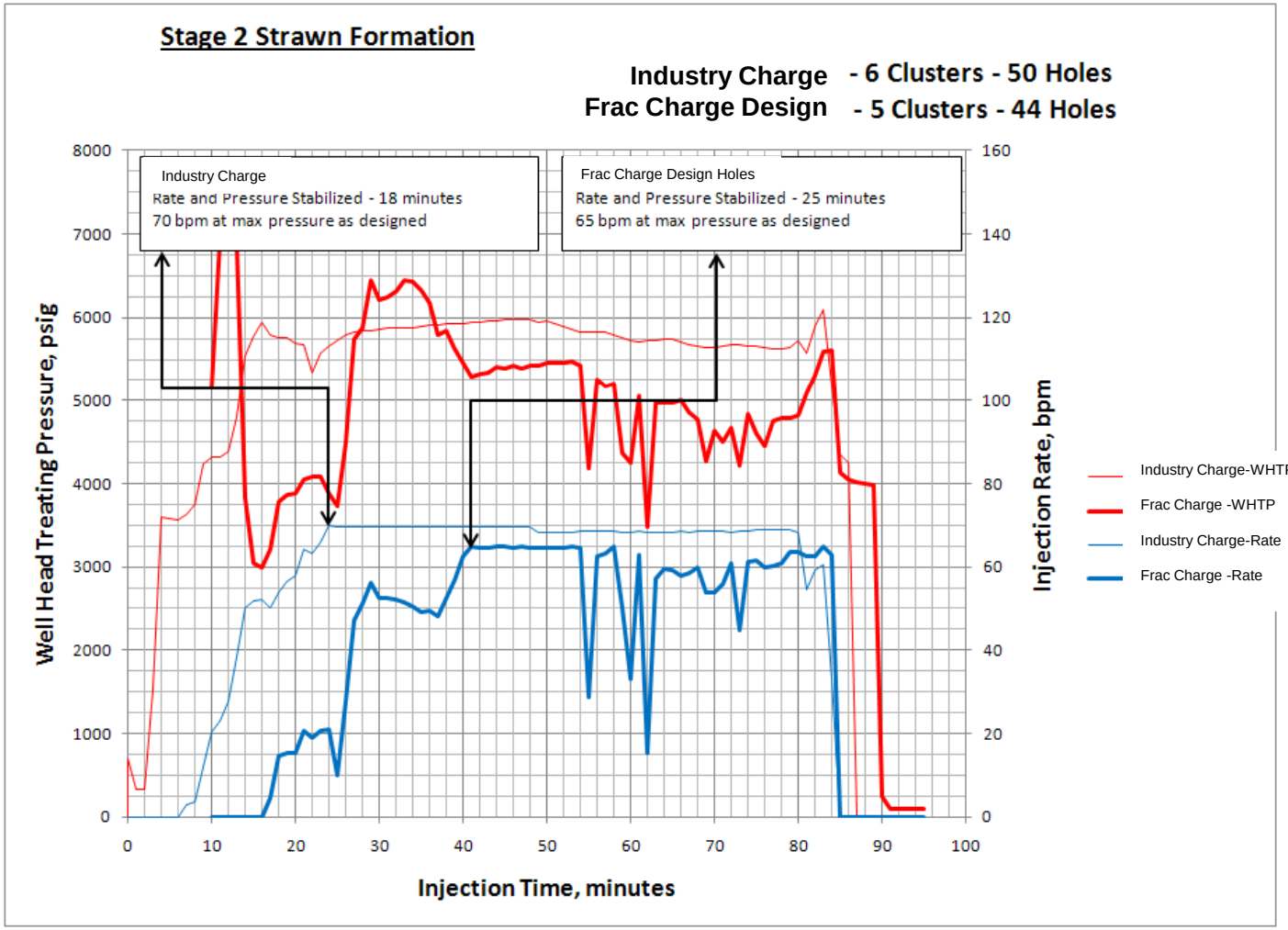
- Comparison of Rate and Pressure Response
  - Test Well reached designed rate and pressure in 25 minutes
    - Third party water transfer could not keep up causing this time to be longer than it should have been and also resulted in erratic rate during the job
  - Benchmark well reached the designed rate and pressure in 18 minutes.

- The 21 gram Frac Charge perforations resulted in a lower treating pressure from 500 to 1000 psig.

Stage #2 Rate and Pressure Overlay

21 gram Frac Charge Design Field Trial #1

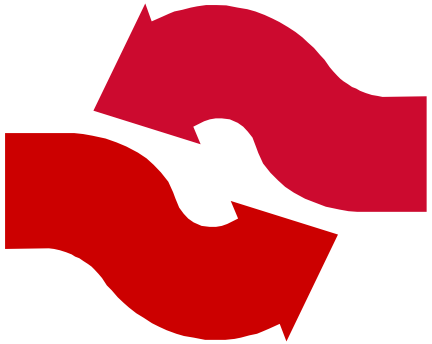
August 8 & 9, 2011 Martin County, Texas



Field Trial #1 Conclusions

- Stage #1
  - The observed injection rate was 15 bpm higher for the same injection pressure for the same number of clusters and number of perforations.
- Stage #2
  - The observed treating pressure was 500 – 1000 psig lower for 1 less cluster and 6 fewer holes.
- Overall
  - The Frac charges have exhibited better performance in terms of rates and pressures than the industry Good Hole charges shot in the baseline comparisons

THANK YOU



Questions and Answers