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

MENAPS 16-08
INTRODUCTION

- Conventional Perforating Systems
  - Entrance hole diameter
- Limited Entry Stimulation
  - The importance of entrance hole diameter
- New Perforating System
  - Constant Entry Hole & Constant Penetration
  - Debris and exit hole analysis
- Impact on Hydraulic Fracturing Perforation Efficiency
  - Step rate test results
  - Comparing conventional and constant entry hole system
- Conclusions
CONVENTIONAL PERFORATING SYSTEMS

- Entrance hole diameter
  - Varies widely with clearance
  - EHD quoted on API published data is an average for a specific casing size
  - Model or test for other casing size/weight/grade

- Penetration
  - Variation in clearance also has an impact on penetration

<table>
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<tr>
<th>Shot No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>304%</td>
<td>477%</td>
<td>304%</td>
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Typical Hole Size Variation in 5-1/2 P-110 23lb Casing

0° 90° 120° 180° 210° 300°
LIMITED ENTRY STIMULATION

- A limited entry type 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
- A higher pressure drop across the perforations (perforation friction) is desireable to encourage distribution of the stimulation treatment to all perforation clusters within the stage - since the amount of perforation friction is critical for the success of this method an accurate estimate of the perforation EHD is important
- If the EHD varies circumferentially then radial distribution of the stimulation can be further compromised as perforation friction through each perforation will be somewhat 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

Perforation friction pressure ($P_{pf}$) can be calculated using the following equation:

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

Where:
- $P_{pf}$ = Perforation friction pressure (psi)
- $q$ = Total pump rate (bpm)
- $\rho_f$ = Slurry density (g/cm$^3$)
- $C_D$ = Perforation discharge coefficient
- $N_p$ = Number of open perforations
- $d_p$ = Perforation diameter (in)
NEW PERFORATING SYSTEM

- A new perforating system offers a constant entry hole and constant penetration solution
- EHD and rock penetration is consistent even though the clearance between the carrier and inner wall of the casing varies
- Options are available with 0.30, 0.35, and 0.40 inch EHD
CONSISTENT PERFORATING SYSTEM

- Entrance hole diameter
  - Predictable and constant in a range of casing sizes, weights, and grades
- Penetration
  - Variation in clearance does not impact the penetration

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Hole Size Variation in 5-1/2 P-110 23lb Casing
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.

- The gun carrier wall interacts with the jet to improve the precision of the created holes in the casing.
CONSISTENT PENETRATION

- **Constant EHD Charge**
  - Sandstone
  - Carbonate
  - Shale

- **Commodity Charge**

- **Premium Charge**

- **Reactive Charge**

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CONSISTENT PENETRATION

- Testing has demonstrated that formation penetration is also consistent at all phase orientations
- To obtain a consistent EHD, formation tunnel length is somewhat reduced as compared to a conventional deep penetrating charge of similar configuration
- Some authors indicate that a reduction in penetration may not adversely affect the completion since less penetration may also result in less formation compaction within the tunnel
  - For a hydraulically fractured completion, break down and treating pressure may be reduced due to a more effective perforation flow path
CARRIER EXIT HOLE

- In order to get consistent performance the exit hole on the carrier is larger
- Larger exit hole diameters on the carrier do not translate to larger entrance holes in the casing
- Strategies have been developed to ensure that charge debris is larger than with conventional systems
  - Debris release can be reduced
**IMPACT ON HYDRAULIC FRACTURING PERFORATION EFFICIENCY**

**Step rate testing**

- Involves pumping a constant fluid into the well at several distinct rates while measuring pump pressure.
- Can predict near-wellbore pressure losses, perforation friction, and the number of open perforations for each stage.
- Predicted surface pump pressure is compared to the actual measured pressure.
  - Calculated surface pressure is adjusted by varying the number of perforations open and the tortuosity to match the measured surface pressure.

![Graph](image-url)

- Predicted surface pressure is compared to the actual measured pressure.
  - Calculated surface pressure is adjusted by varying the number of perforations open and the tortuosity to match the measured surface pressure.

**Graph Description**

- The graph shows the relationship between rate (lpm) and pressure (psi).
- The data points represent different stages and rates, with varying pressures observed.
- The trend lines indicate the expected pressure response to different injection rates.

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IMPROVED HYDRAULIC FRACTURING PERFORATION EFFICIENCY OBSERVED WITH CONSTANT ENTRY HOLE AND CONSTANT PENETRATION PERFORATING SYSTEM
Example 1

- Williston Basin – Bakken formation
- Well completed with 43 perforated stages
- 4-1/2 inch casing
- Two different conventional systems were used in alternating stages with a consistent EHD perforating system
- In each case the number of perforations shot per stage/cluster was adjusted to provide approximately the same area open to flow for each stage based on the supplied/predicted entrance hole diameter
- Step rate tests were conducted pre-acid, post-acid, and post-frac for each stage.
- Analysis of post-acid data determined that stages completed with a conventional charge showed perforation efficiency (the ratio of the number of holes open to the total number holes per stage) ranged from 44-70 percent
- The consistent EHD system perforation efficiency exceeded 80 percent
- Near wellbore tortuosity was consistently low with each perforating system
Example 2

- Williston Basin – Three Forks formation
- Well completed with 39 perforated stages
- 4-1/2 inch casing
- As with Example 1 - different conventional systems were used in alternating stages with a consistent EHD perforating system
- In each case the number of perforations shot per stage/cluster was adjusted to provide approximately the same area open to flow for each stage based on the supplied/predicted entrance hole diameter
- Step rate tests were conducted pre-acid, post-acid, and post-frac for each stage.
- Perforation efficiency for the conventional system ranged from 51-66 percent, depending on the system configuration – perforation efficiency for the consistent system averaged 80 percent
- Near wellbore tortuosity was consistently low with each perforating system
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.
- A design based off a conventional perforation system can provide misleading results - if proppant selection is based off the average perforation EHD then the holes which are smaller than this average diameter may actually screen out.
- Accurate step rate testing allows for future optimization of the completion and treatment plan. Consistent EHD charges provide higher perforation efficiency compared to conventional perforating charges run on the same well.
- This new perforating system eliminates the variable EHD of conventional systems and has the potential to provide even flow distribution and velocity through all open perforations since the diameter, erosion, and penetration will be consistent.
- All perforations have an equal chance of accepting stimulation since the pressure drop across any single perforation is the same.
QUESTIONS?
THANK YOU!