Multi Cluster Perforation Design
Parameters Optimization

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Outline

1. Introduction
2. Instruction of Multi Cluster Perforation
3. Optimization of Multi Cluster Perforation Parameters
4. Application of optimization
5. Conclusions and Suggestions
Exploration of unconventional oil and gas

- Horizontal well has become the main exploring method in unconventional oil gas fields.

Multi cluster perforation as the primary supporting technology.
- Producing good passages for fracturing
- Operation safety and efficiency

A method combining theoretical analysis and application result to optimize perforation design can improve succeeding rate and safety of multi cluster perforation, and providing best precondition for fracturing.
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Optimization of Multi Cluster Perforation Parameters

- Density
- Phase
- Hole Diameter
- Section Length
- Cluster Number

Optimization of parameters

Fracturing effect

Success rate

Pumping down Parameter

Throughput capacity

Tool string
Optimization of Multi Cluster Perforation Parameters

Perforation density optimization

Perforation hole friction: \[ \Delta P = 2.2326 \times 10^{-10} \frac{q^2 \rho}{n^2 d^4 c^2} \]

From above equation, shooting density and hole diameter affect perforation hole friction the most. Therefore, increasing shooting density and hole diameter can decreasing perforation hole friction effectively. This can also increase maxim pumping rate and sand carrying ability, which is favor for fracturing.

In shooting density design, common perforation gun type, perforation length, fracturing rate, limit entry requirements, and other demands in fracturing design should also be considered.
Optimization of Multi Cluster Perforation Parameters

Perforation density optimization

Pumping rate--hole diameter--hole number relationship

<table>
<thead>
<tr>
<th>Pumping Rate</th>
<th>Hole Diameter</th>
<th>Recommended Hole Number (Flowing rate 0.7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Δ P&lt;0.2 MPa</td>
</tr>
<tr>
<td>2 m³/min</td>
<td>10 mm</td>
<td>30孔</td>
</tr>
<tr>
<td></td>
<td>20 mm</td>
<td>8孔</td>
</tr>
<tr>
<td></td>
<td>30 mm</td>
<td>4孔</td>
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<td>4 m³/min</td>
<td>10 mm</td>
<td>60孔</td>
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<td></td>
<td>20 mm</td>
<td>16孔</td>
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<tr>
<td></td>
<td>30 mm</td>
<td>8孔</td>
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<tr>
<td>6 m³/min</td>
<td>10 mm</td>
<td>90孔</td>
</tr>
<tr>
<td></td>
<td>20 mm</td>
<td>24孔</td>
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<td>10 m³/min</td>
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<td></td>
<td>20 mm</td>
<td>38孔</td>
</tr>
<tr>
<td></td>
<td>30 mm</td>
<td>18孔</td>
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</table>
Optimization of Multi Cluster Perforation Parameters

When perforation phases are 45°, 60°, 90° and 180°, maxim perforation direction angles are 22.5°, 30°, 45°, and 90°.
Optimization of Multi Cluster Perforation Parameters

Perforation phase Optimization

When formation stress direction is not accurately measured, helical shot pattern should be applied to decrease formation breaking pressure.

Breaking pressure of different density when phase is 90°  
Breaking pressure of different density when phase is 180°
Optimization of Multi Cluster Perforation Parameters

Section length and cluster number optimization

Fracturing effect

Section length

Work Requirement

Low formation stress section

Difference of stress between each cluster be low

Cluster number
Optimization of Multi Cluster Perforation Parameters

Optimization of pumping down procedure

Friction Force \( F_f = \mu N \)  
Pushing Force \( F_c = \rho A v^2 \)

For the whole well of pumping section, should dynamically adjust speed and pumping rate, to control the force applied on the tool string.
Optimization of Multi Cluster Perforation Parameters

When tool string stops running, the follow conditions should be satisfied:

\[ OA^2 = AB^2 + OB^2 \]
\[ OE^2 = DE^2 + OD^2 \]

Therefore, maximal tool string length is:

\[ L_{\text{max}} = AB + DE = \sqrt{(R + R_1)^2 + (R + R_1 + R_2)^2} \]
CNH3 well group have 3 horizontal wells, using “factory” working pattern. Completion casing OD. is 5”, casing ID. is 102.72mm. Perforation tool string is 3 perforation guns plus 1 composite plug or 4 perforation guns plus 1 composite plug. Perforation gun OD. is 73mm, loading type 73 “Xianfeng” shaped charges. The string length is 14.5m–16m, weight is 400 KG。
Application of optimization

Length of section and cluster number optimization

- Lithomechanics Analysis
- Formation tress Analysis
- Rock fragility Analysis
- Formation sensibility Analysis
- Fracture height expansion Analysis

Logging data, 3D seismic data etc.
Application of optimization

**Length of section and cluster number optimization**

**CNH3–1**
- Near point A: Length of section was optimized to 80m.
- Near point B: Length of section was optimized to 100m.

**CNH3–2**
- Length of section was optimized to 90m-100m evenly in whole horizontal section.

**CNH3–3**
- Good Cementing quality portion: Length of section was optimized to 60m-70m.
- Other portion: Length of section was optimized to 150m-200m.

Cluster number was optimized by summary of local successful experience. The result was to shoot 3 clusters for segment length within 100m, and 4 clusters for segment length 150m-200m. Cluster in one segment was evenly distributed.
Application of optimization

Perforation density and phase optimization

According to total discharging rate, single hole discharging rate, hole friction, and hole efficiency, a 48 hole per section density was optimized. From results of optimizing software, 16 spm and 12 spm was chosen, phase was 60°.
Application of optimization

Tool string optimization

### CNH3-1 Well deviation data

<table>
<thead>
<tr>
<th>Num</th>
<th>MD (m)</th>
<th>Incl (°)</th>
<th>Azim Grid (°)</th>
<th>TVD (m)</th>
<th>DLS (°/25m)</th>
<th>Closure Azimuth (°)</th>
<th>Closure (m)</th>
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<tbody>
<tr>
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<td>93.03</td>
<td>11.35</td>
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### CNH3-2 Well deviation data

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<th>DLS (°/25m)</th>
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<tbody>
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<td>157</td>
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### CNH3-3 Well deviation data

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<th>Incl (°)</th>
<th>Azim Grid (°)</th>
<th>TVD (m)</th>
<th>DLS (°/25m)</th>
<th>Closure Azimuth (°)</th>
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<tr>
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Application of optimization

Tool string optimization

According to perforation requirements and estimated well head pressure, the optimized tool string length was about 15.5m.

Tool string length of throughput capacity is 14m–16m.

Increase safety

Knuckle joint was adding to the tool string

Rigid tool length is 13m.
In this well group, horizontal section were all up-warping, the biggest deviation were 98.26°, 98.09°, and 99.89°. In this situation, pumping rate should be adjusted adequately. The designed maximum pumping rate not exceeding 2.5m³/min, the speed is about 2000m/h, Cable head tension is about 1KN.
Application of optimization

Actual operations

Using the optimized pumping down design, all pumping down operations were steady in 3 wells, all 29 pumping down operations were successful at the first time.
Introduction

Instruction of Multi Cluster Perforation

Optimization of Multi Cluster Perforation Parameters

Application of optimization

Conclusions and Suggestions
Every step of perforation can affect operation effect. It is important to optimize key parameters of multi cluster perforation prior operation according to all basic data.

1. Make several possible designs according to actual operation conditions and application results, and then evaluate working effect and task achieving situation to find the best perforation parameters.

2. Tool string parameter should satisfy both operation requirements and throughput capability. Optimizing tool sting can increase working succeeding rate and safety.

3. Pumping down takes the most risk in multi cluster perforation, as its process is complex and there are plenty of affecting parameters. Pumping down parameters optimization should combine theoretical and actual conditions to ensure pumping down safety and efficiency.
Thank You!