中国石油天然气集团公司
CHINA NATIONAL PETROLEUM CORPORATION

Multi Cluster Perforation Design Parameters Optimization

Ren Guohui

CNPC, CCDE Well Logging Company

2014. 10 Sanya

Out line

Introduction

Exploration of unconventional oil and gas

Unconventional oil and gas

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

Multiple stage fracturing

Multi cluster perforation as the primary supporting technology 。

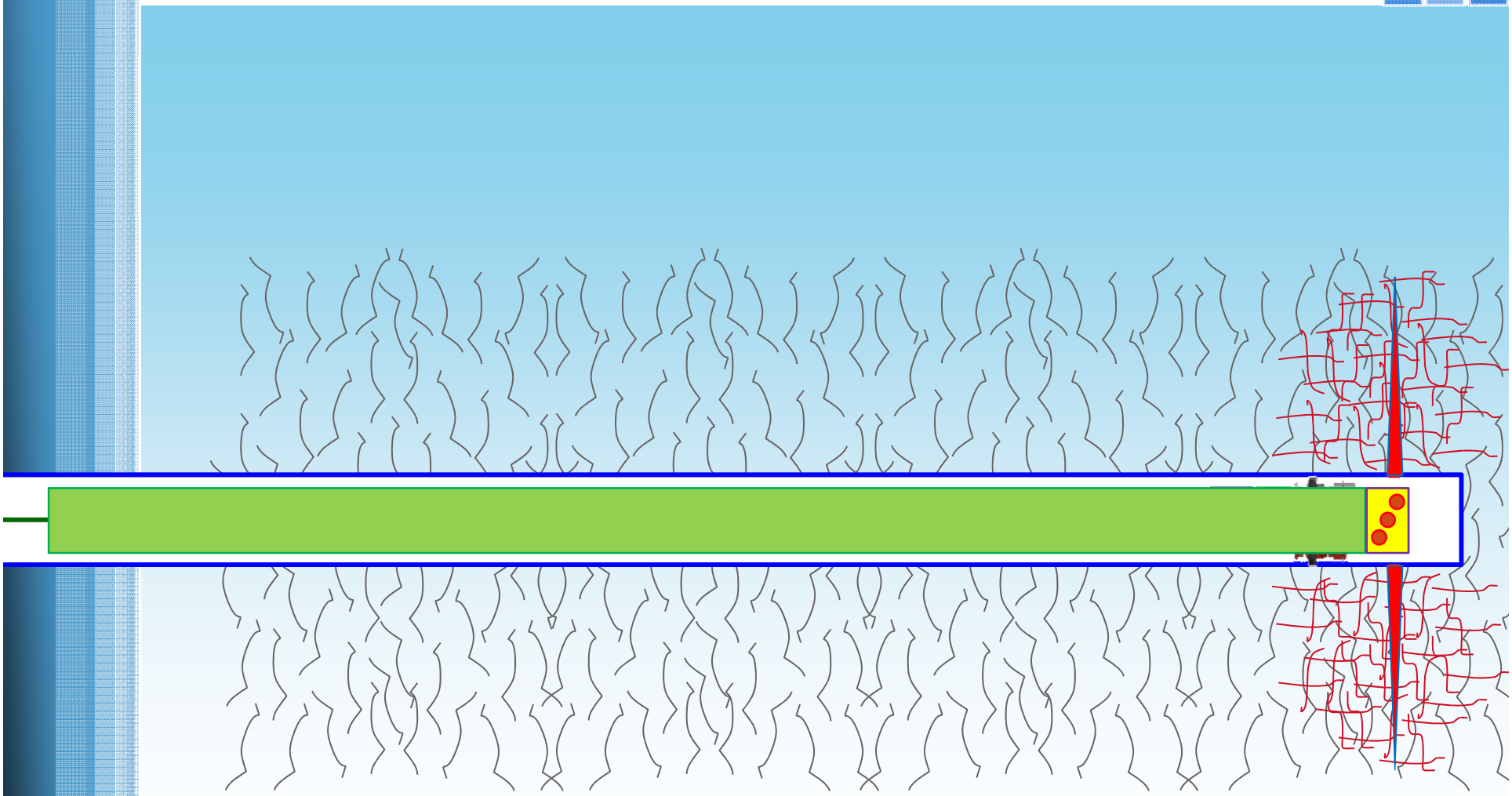
- Producing good passages for fracturing
- Operation safety and efficiency

Design Parameters Optimization

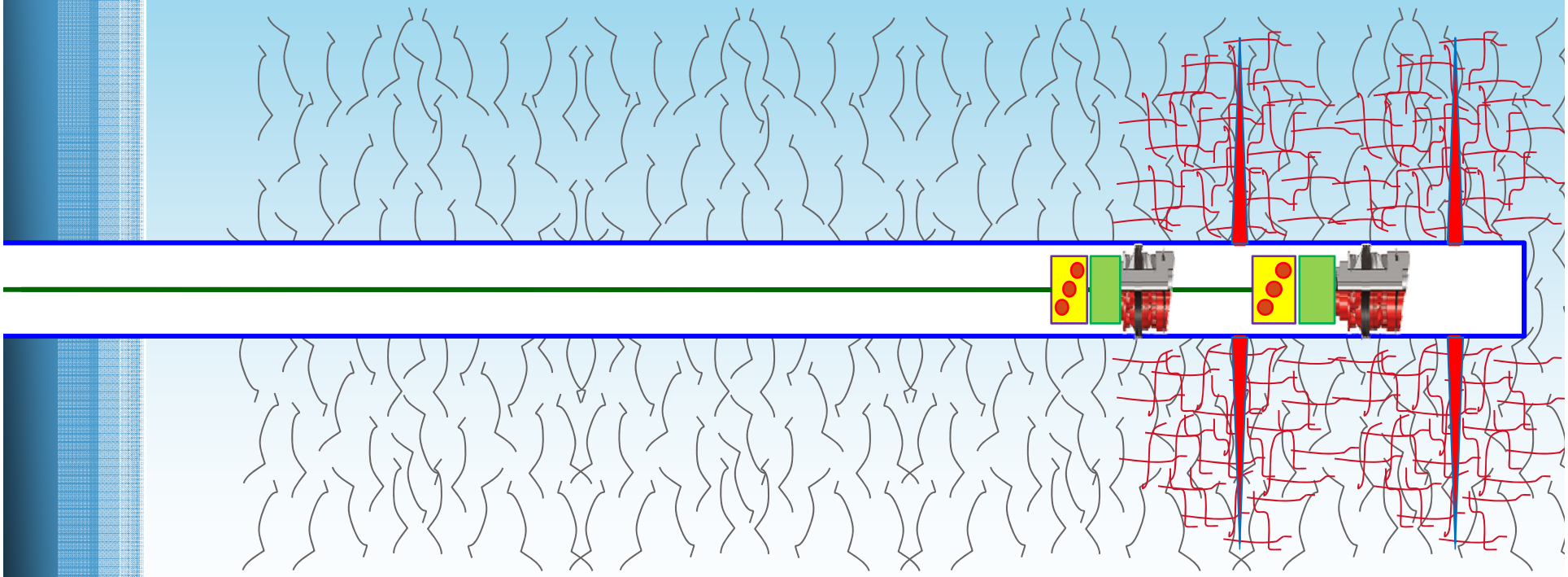
A method combining theoretical analysis and application result to optimize perforation design can improve succeeding rate and safety of multi cluster perforation, and providing best precondition for fracturing.

Out line

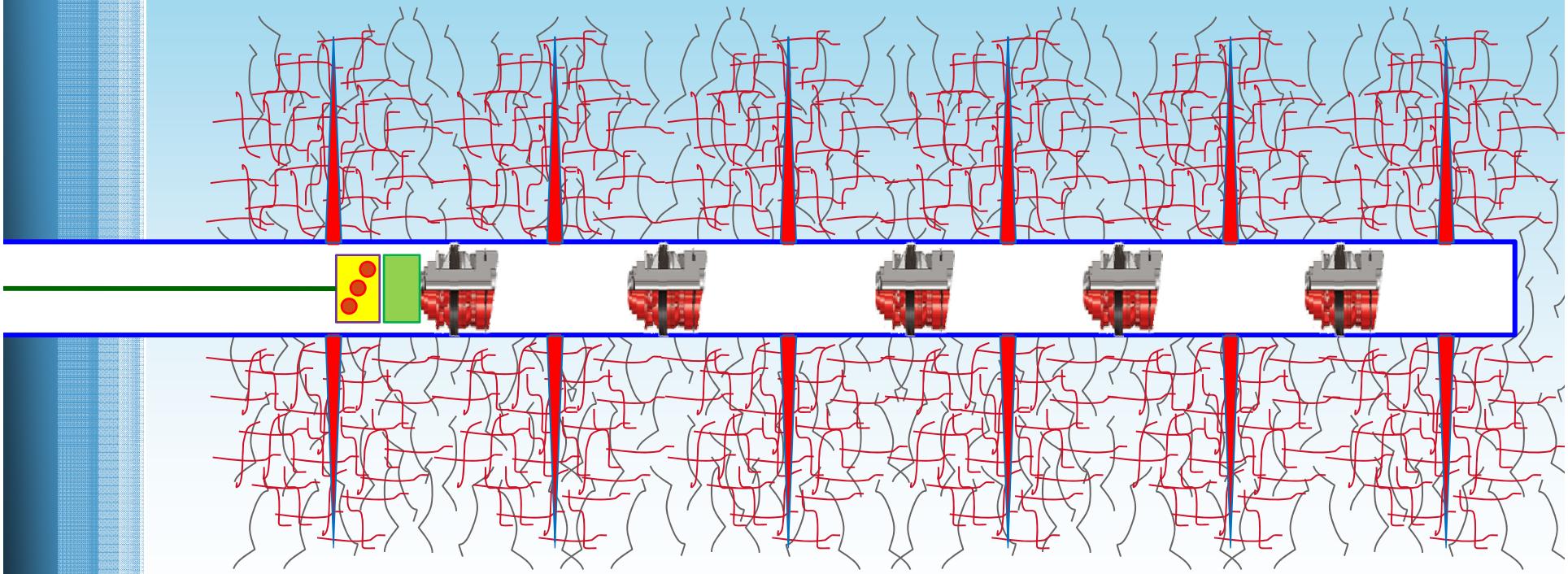
Instruction of Multi Cluster Perforation



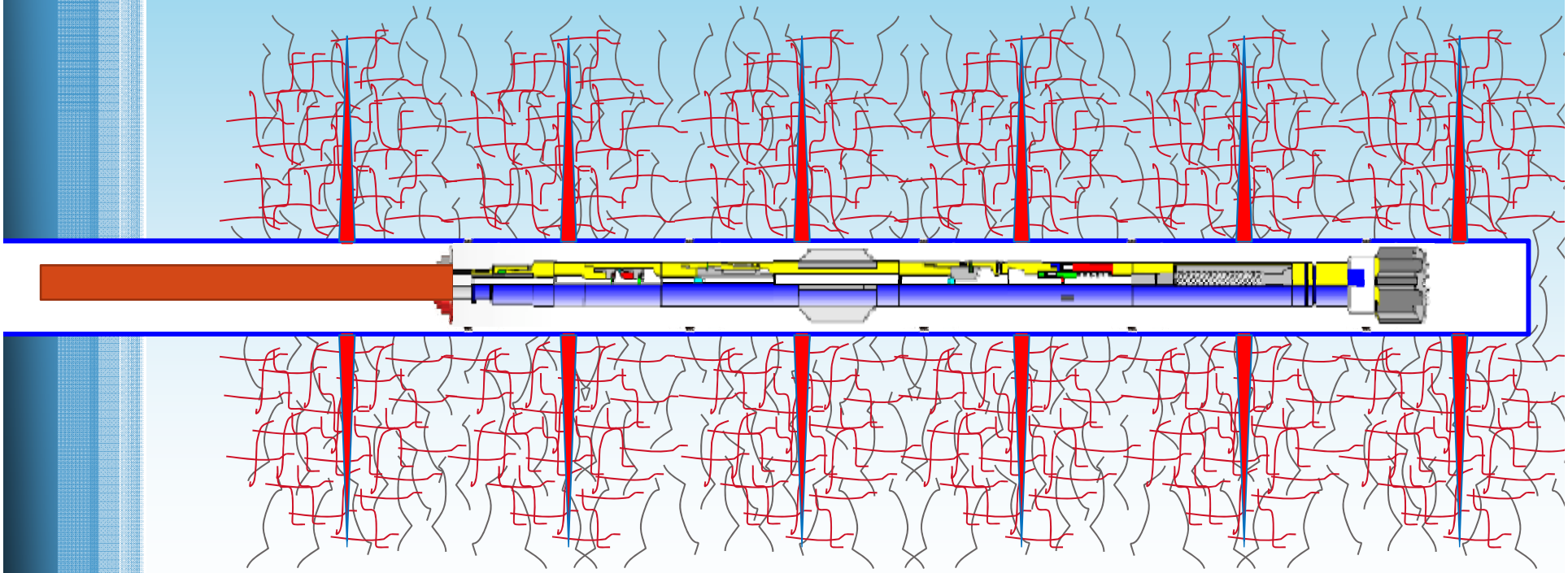
Instruction of Multi Cluster Perforation



Instruction of Multi Cluster Perforation



Instruction of Multi Cluster Perforation



Out line

Optimization of Multi Cluster Perforation Parameters

Optimization of parameters

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

→ Fracturing effect → Success rate ←

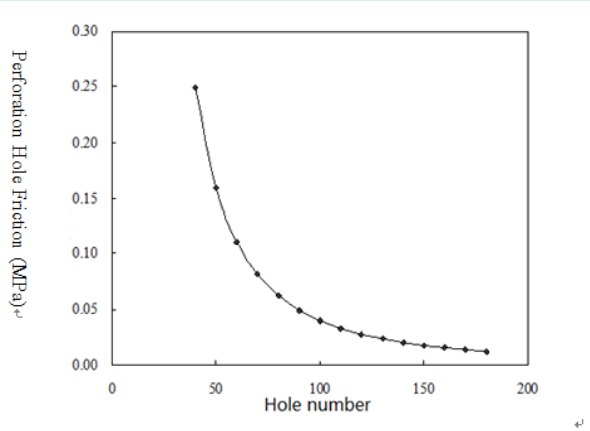
- Pumping down Parameter
- Tool string Throughput capacity

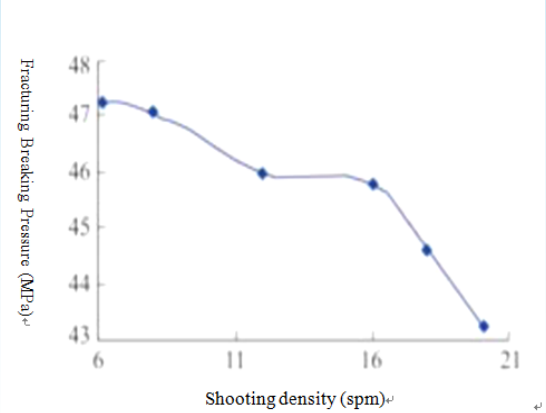
Optimization of Multi Cluster Perforation Parameters

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

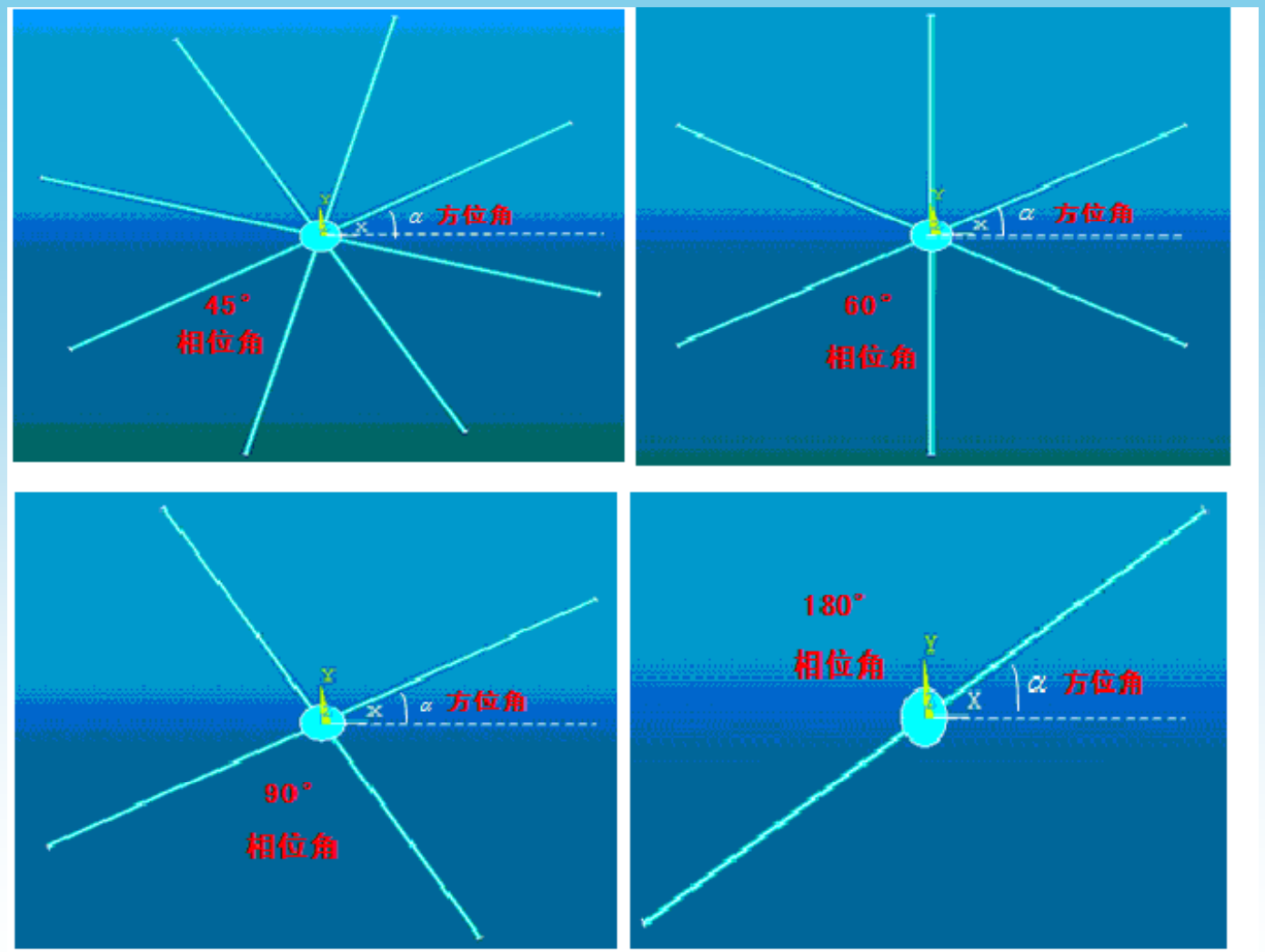
Perforation density optimization

Pumping rate--hole diameter--hole number relationship

Pumping Rate	Hole Diameter	Recommended Hole Number(Flowing rate0.7)		
		ΔP<0. 2MPa	ΔP<0. 4MPa	ΔP<0. 8MPa
$2m^3/min$	10mm	30孔	22孔	16孔
	20mm	8孔	6孔	4孔
	30mm	4孔	4孔	2孔
$4m^3/min$	10mm	60孔	42孔	32孔
	20mm	16孔	12孔	8孔
	30mm	8孔	6孔	4孔
$6m^3/min$	10mm	90孔	64孔	46孔
	20mm	24孔	16孔	12孔
	30mm	10孔	8孔	6孔
$8m^3/min$	10mm	120孔	86孔	62孔
	20mm	32孔	22孔	16孔
	30mm	14孔	10孔	8孔
$10m^3/min$	10mm	150孔	106孔	76孔
	20mm	38孔	28孔	20孔
	30mm	18孔	12孔	10孔

Optimization of Multi Cluster Perforation Parameters

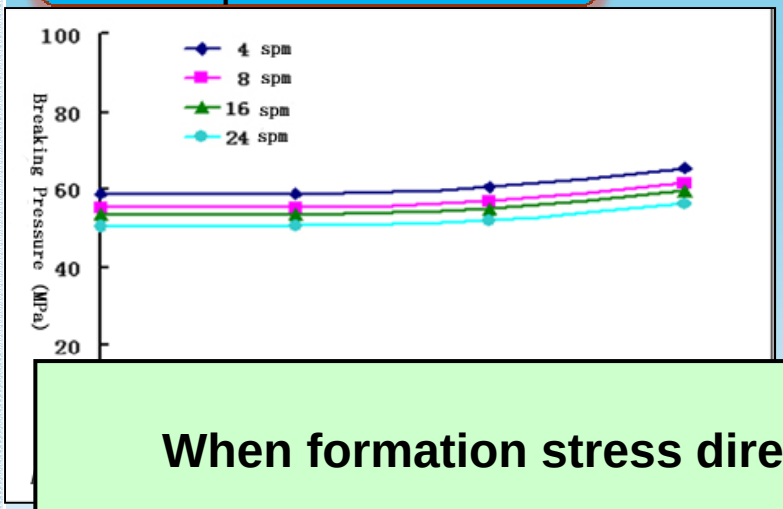
Perforation phase Optimization

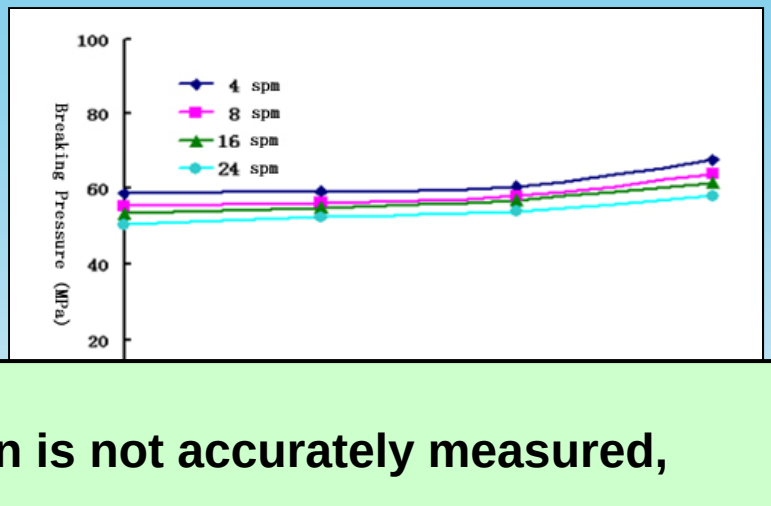


When perforation phases are 45°, 60°, 90° and 180°, maxim perforation direction angels are 22.5°, 30°, 45°, and 90°

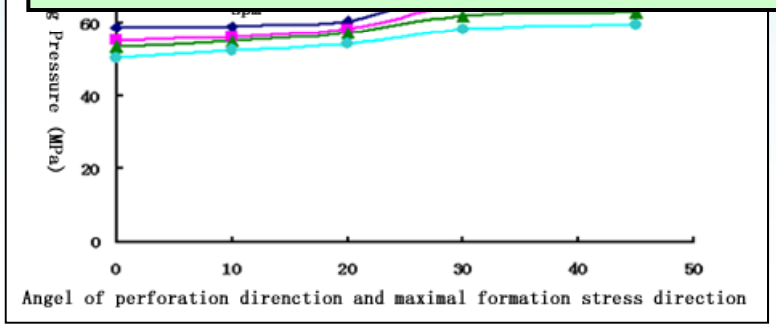
Optimization of Multi Cluster Perforation Parameters

Perforation phase Optimization

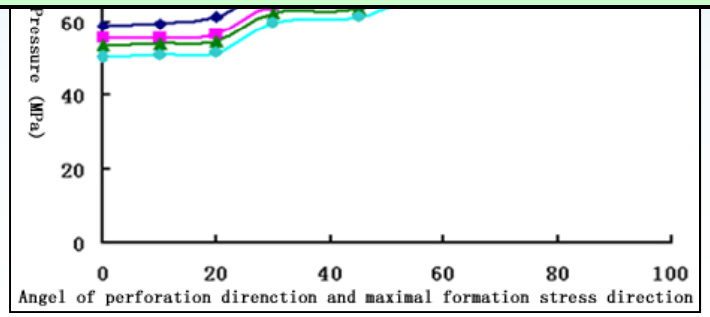




When formation stress direction is not accurately measured, helical shot pattern should be applied to decrease formation breaking pressure.



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

Section length

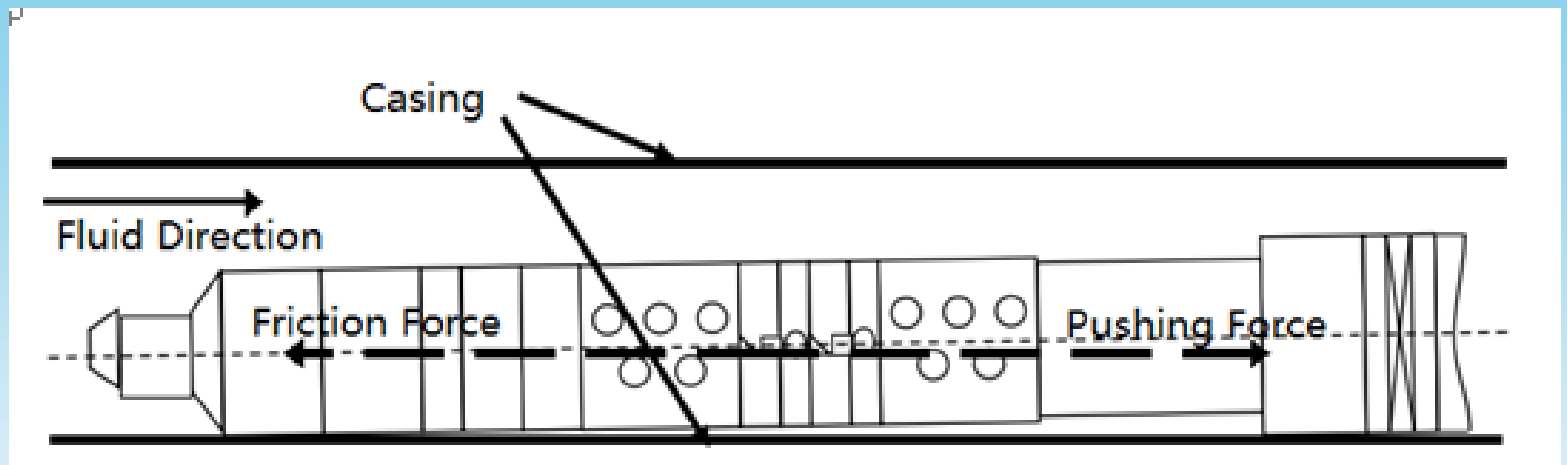
- Fracturing effect
- Work Requirement

Cluster number

- Low formation stress section
- difference of stress between each cluster be low

Optimization of Multi Cluster Perforation Parameters

Optimization of pumping down procedure



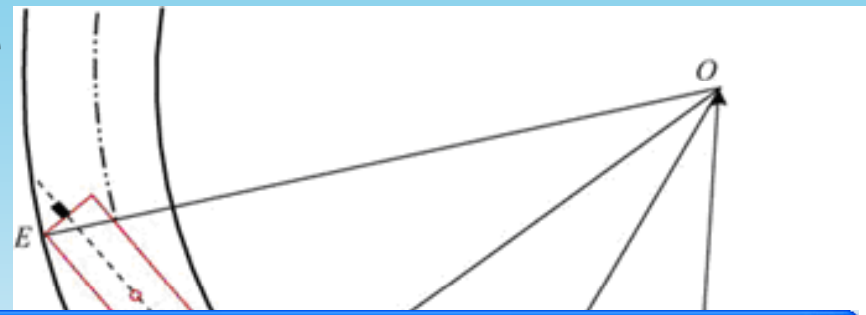
Friction Force $F_f = \mu N$ Pushing Force $F_c = \rho A v^2$

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

Optimization of Multi Cluster Perforation Parameters

Optimization of tool string throughput capacity

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

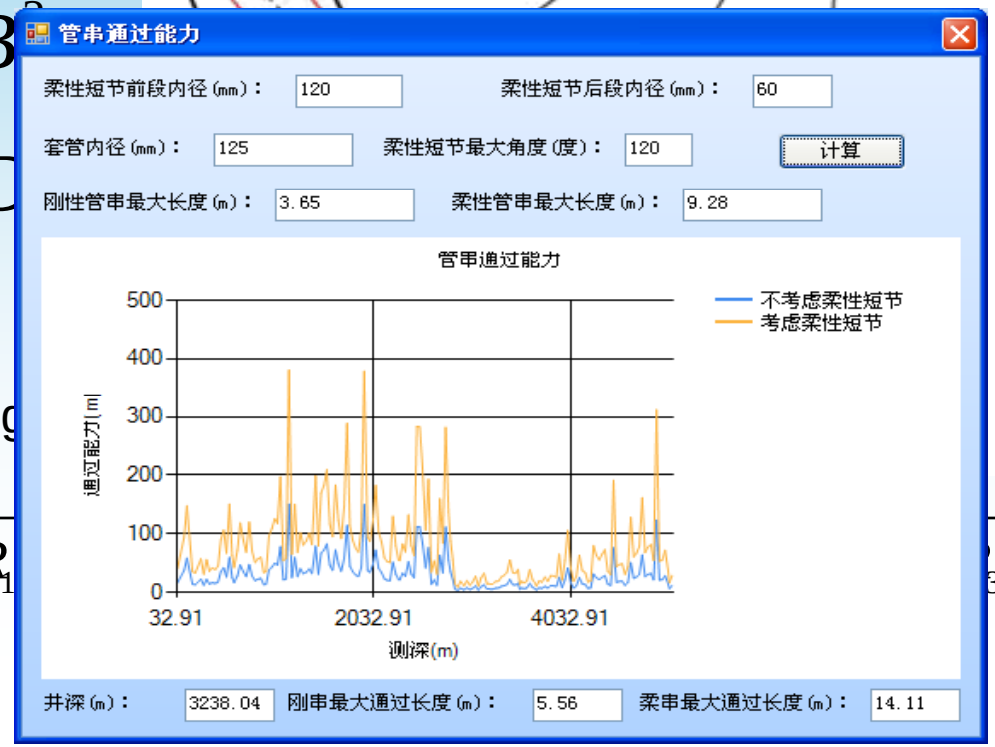


$$OA^2 = AB^2 + OB$$

$$OE^2 = DE^2 + OD$$

Therefore, maximal tool string

$$L_{\max} = AB + DE = \sqrt{(R + R_1}$$



Out line

Application of optimization

CNH3 well group

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

Logging data, 3D seismic data etc.

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

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 。

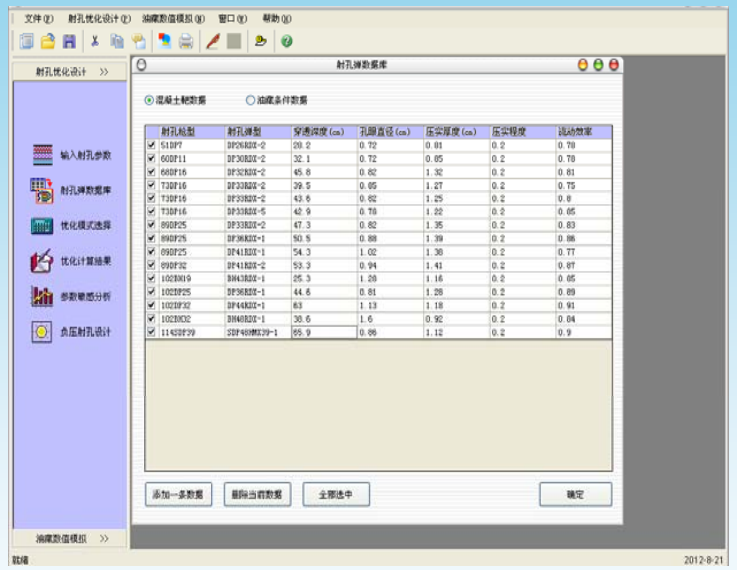
CNH3-2 → Length of section was optimized to 90m-100m evenly in whole horizontal section.

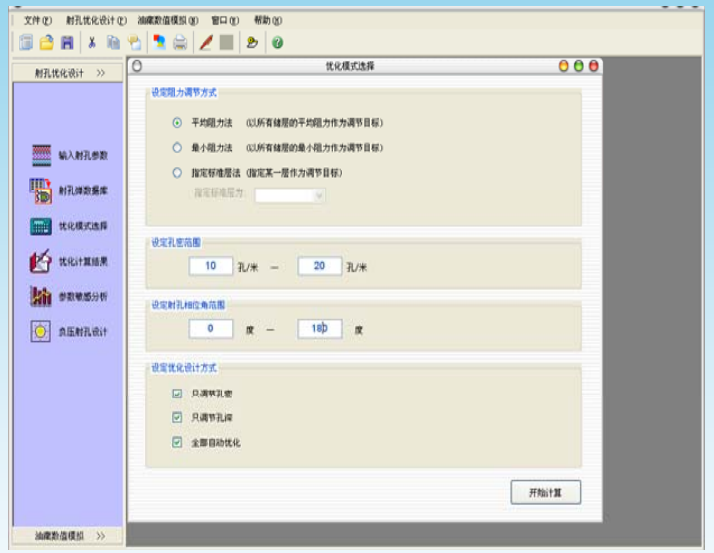
CNH3-3 → Good Cementing quality portion: Length of section was optimized to 60m-70m； Other portion : Length of section was optimized to 150m-200m

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

CNH3-1Well deviation data

Num	MD (m)	Incl (°)	Azim Grid (°)	TVD (m)	DLS (°/25m)	Closure Azimuth (°)	Closure (m)
125	3043.47	93.03	11.35	2490.54	1.69	64.41	830.61
133	3207.13	97.12	12.25	2475.36	1.47	56.24	934.44
147	3572.83	98.26	11.65	2432.11	0.34	43.74	1213.87

CNH3-2Well deviation data

Num	MD (m)	Incl (°)	Azim Grid (°)	TVD (m)	DLS (°/25m)	Closure Azimuth (°)	Closure (m)
135	2853.11	89.82	9.45	2475.06	7.11	53.2	570.01
157	3207.25	94	11.15	2443.16	1.61	37.7	867.21
162	3321.88	98.09	12.95	2431.41	1.37	34.78	971.16

CNH3-3Well deviation data

Num	MD (m)	Incl (°)	Azim Grid (°)	TVD (m)	DLS (°/25m)	Closure Azimuth (°)	Closure (m)
94	2685.85	90	10.5	2464.25	15.16	9.86	422.87
96	2721.08	92.94	10.15	2463.32	2.38	9.89	458.08
98	2766.25	99.89	10.85	2457.45	1.46	9.96	502.83

Application of optimization

Tool string optimization

Tool string length of throughput capacity is 14m-16m。

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

Increase safety

Knuckle joint was adding to the tool string

Rigid tool length is 13m.

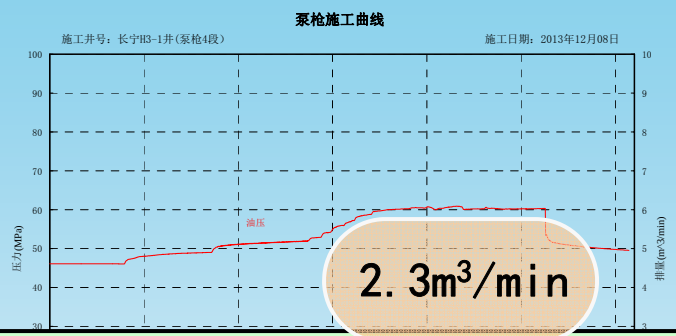
Application of optimization

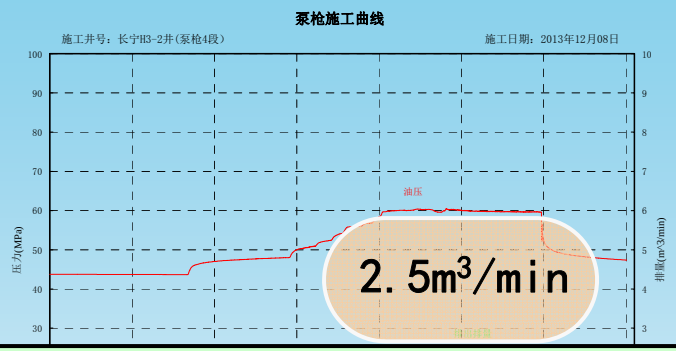
Optimization of pumping down procedure

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 2.5m^3/min， the speed is about 2000m/h，Cable head tension is about 1KN。

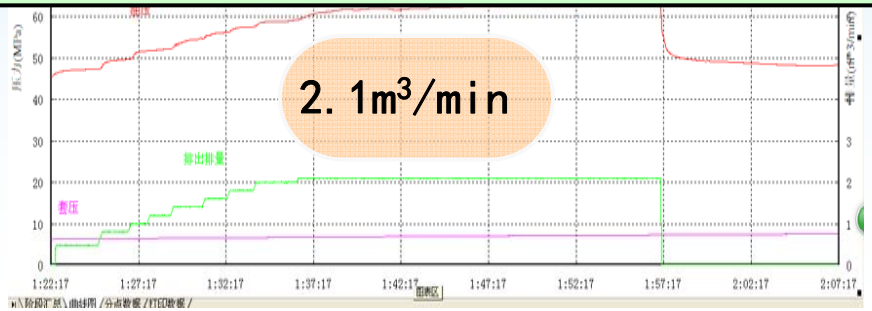
Application of optimization

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.



H3-3Pump curve

Out line

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.

中国石油

奉献能源 创造和谐

www.cnpc.com.cn

Thank You!