Triple-Jet Perforating Technology and Its Application

Daqing Oilfield Co., Ltd

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Introduction

At present, as Daqing Oilfield has entered the later period of high water cut development, the difficulty of exploration and development is increasing such that higher requirements are proposed for perforating technologies. The conventional perforating makes use of high pressure and high velocity metal jets created by perforating charges to penetrate casing and cement to enter the formation for a certain depth. Because the tunnels are created by squeezing, a compact zone with much reduced permeability is formed around the tunnel, the permeability of which is only 30 percent of that of the original formations, which impacts to a certain extent on the diversion performation of the tunnels. To improve the development results in polymer drive, three-elements drive, and crude oil wells, the tunnel diameter shall be increased; and also to improve development results in low permeability peripheral oil fields, the perforation depth shall be increased. Under the above conditions, the triple-jet perforating technology is developed.

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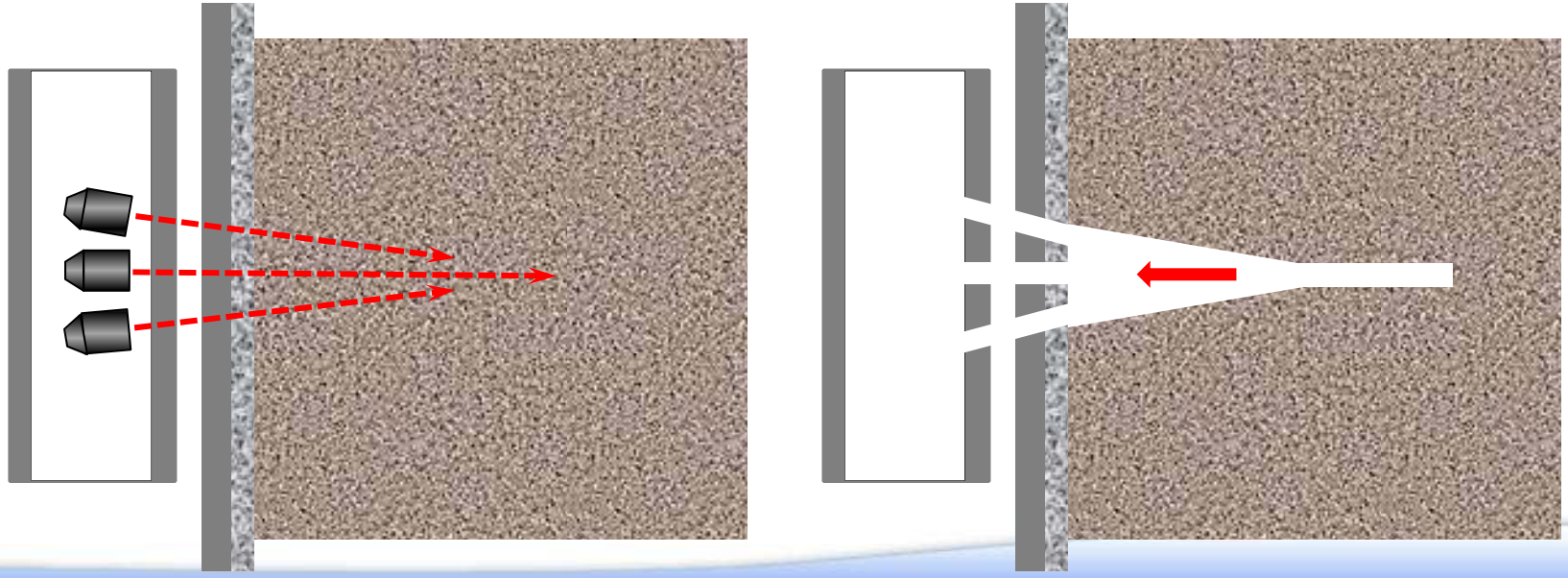
1. Technical Principle and Features

Technical Principles

By firing a bank of three co-linear focused charges, the jets from the upper and lower perforating charges are angled to intersect within the formation. While the tunnel is created, the formation stress between the tunnels is released. The center charge is slightly delayed and with the beneficial effect of the altered stress, the penetration and diversion area are greatly increased, thus to improve the flow efficiency and the productivity of the wells.



1. Technical Principles and Features

Technical Features

（1）The triple-jet perforating employs conventional shaped charges and its operation is the same as that of conventional perforating method.

（2）With large diameter, longer tunnels, and removed crushed zone, it is easier to clean perforation tunnels when operated with dynamic underbalanced perforating.

（3）Angularly focused perforating charges create the same entry hole diameter as the conventional charges, which has no influence on casing strength .

（4）It produces better application results.

（5）It’s suitable for vertical well, deviated well and horizontal well.

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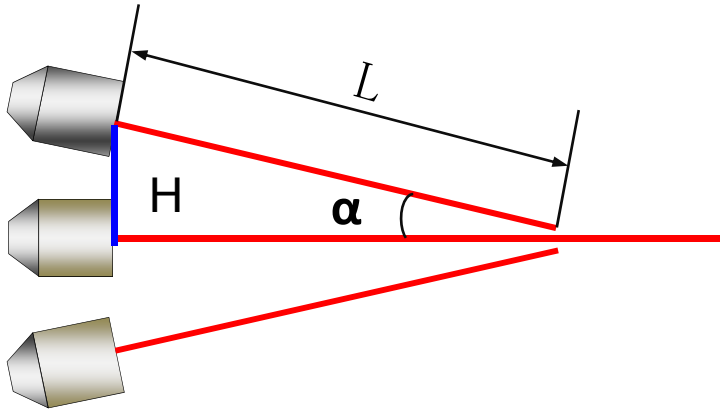
2. Triple-jet Perforator Design

Structure Design (Charge Cartridge）

（1）Calculate intersection angle α between adjacent perforation jets based on perforation depth L and spacing distance H between adjacent shaped charges.

（2） Based on angle α, a combined molding built-in cartridge with high temperature rating is designed, which ensures each group of jets is on the same plane, and the angles between the jets are accurate, while the guns can be armed easily and rapidly.



Intersection angle design of triple-jet perforating charges

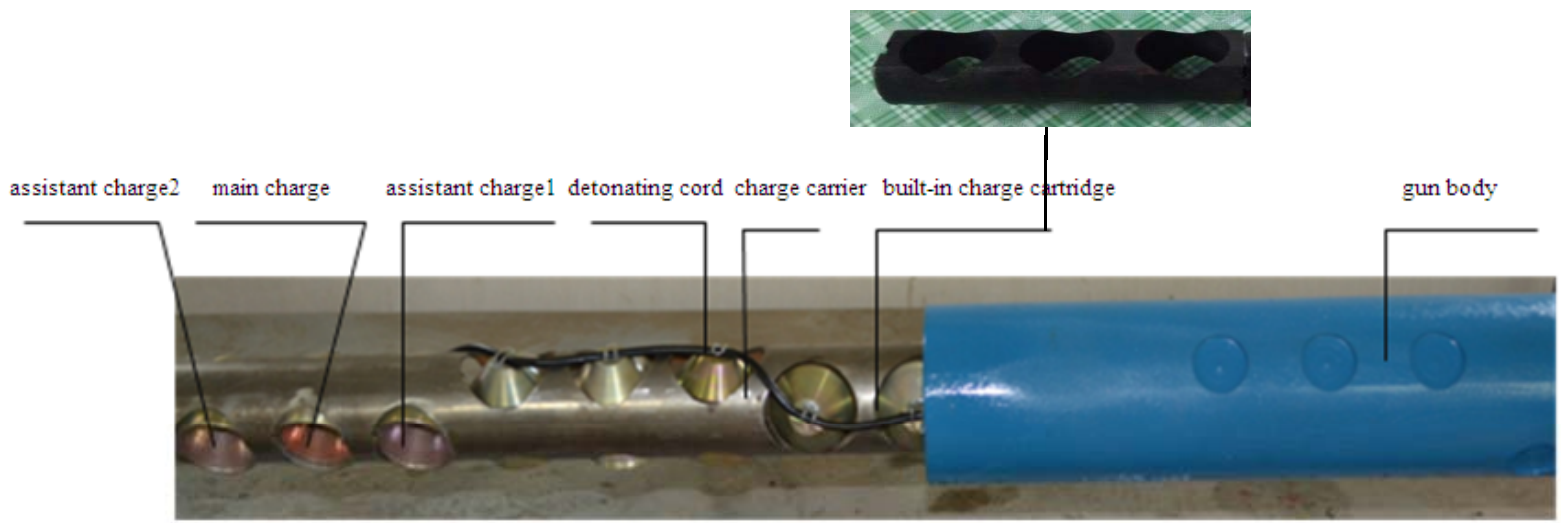
Combined charge cartridges of triple-jet perforating

2. Triple-jet Perforator Design

Structure Design (Gun body)

（1）It is composed of gun body, built-in cartridge, charge carrier, detonating cord, assistant charge 1, assistant charge 2, and a main charge, etc.

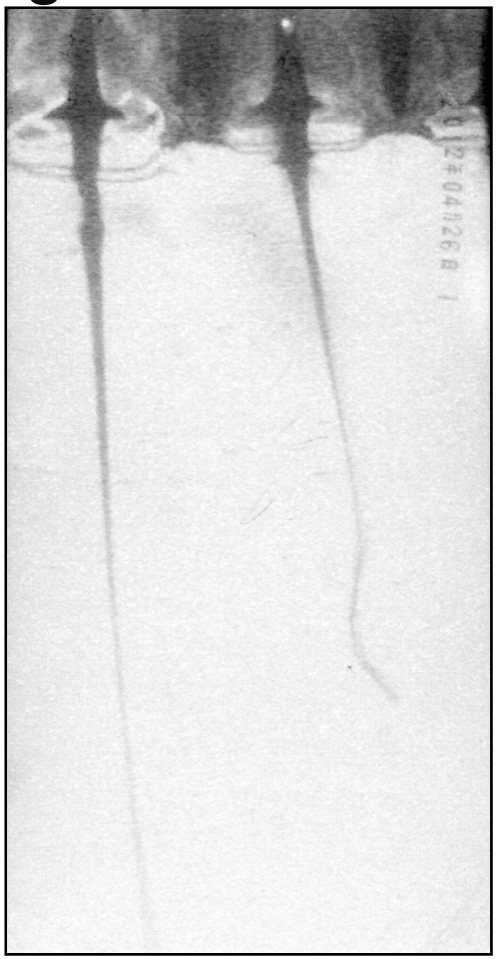
（2）The perforator is 5 phases, phase angle 72°, 5 sets/m, and shot density 15 shots/m.

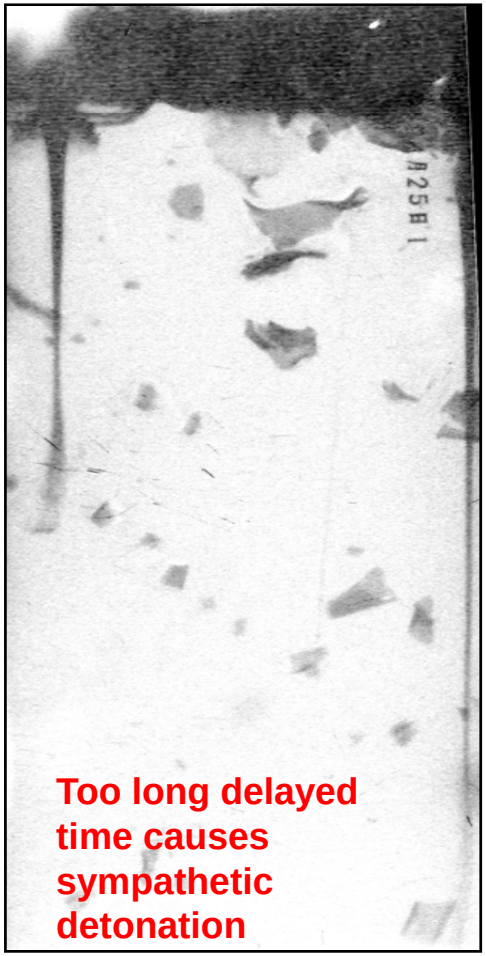


2. Triple-jet Perforator Design

Delayed Detonating Design

The key technical factor to the triple-jet perforating is to control the delayed time of detonating for the center charge in each set (3 charges) of the perforating charges. Too early detonating will reduce perforating results, and too late will cause charge interference or sympathetic detonation.





X-ray test of triple-jet perforating charges

2. Triple-jet Perforator Design

Delayed Detonating Design

Through theoretical calculation, study and experiment of jets from the main charge and the delayed charge, the delayed detonating time is determined. After a lot of X-ray detection, the technology has met the technical requirements, achieving accurate control of the time sequence for the three charges in triple-jet perforating, which not only eliminates charge interference, but also improves the penetration.

Explosion direction →

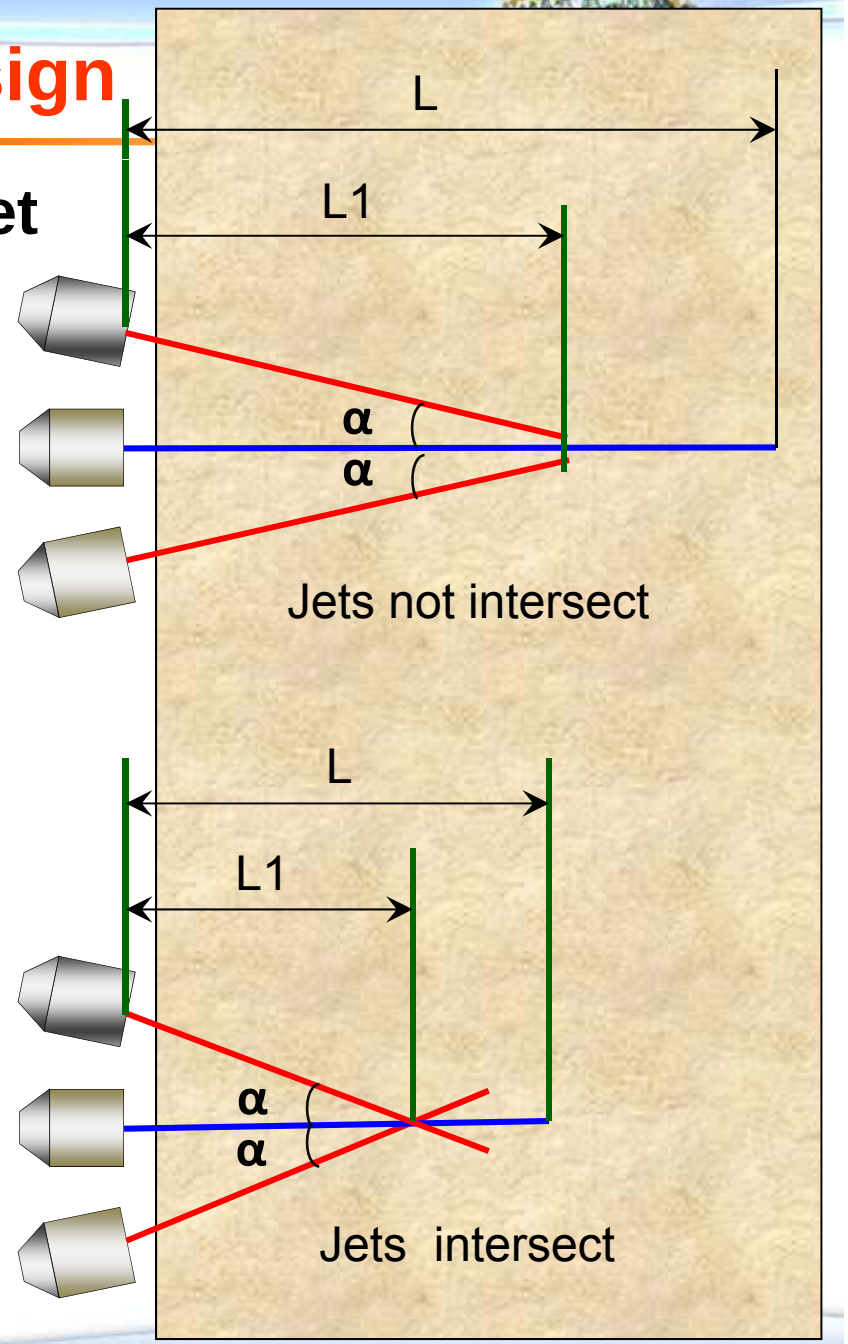
Time delay test of triple-jet perforating

2. Triple-jet Perforator Design

Angle Design of the Focused Jet

The best focused angle is that the tips of the upper and lower assistant perforating tunnels close to, but not intersect; and also the three jets shall be ensured on the same plane.

If two jets intersect within the formation, they will cause collision such that not only the penetration of the two jets, but also the total depth will be reduced.



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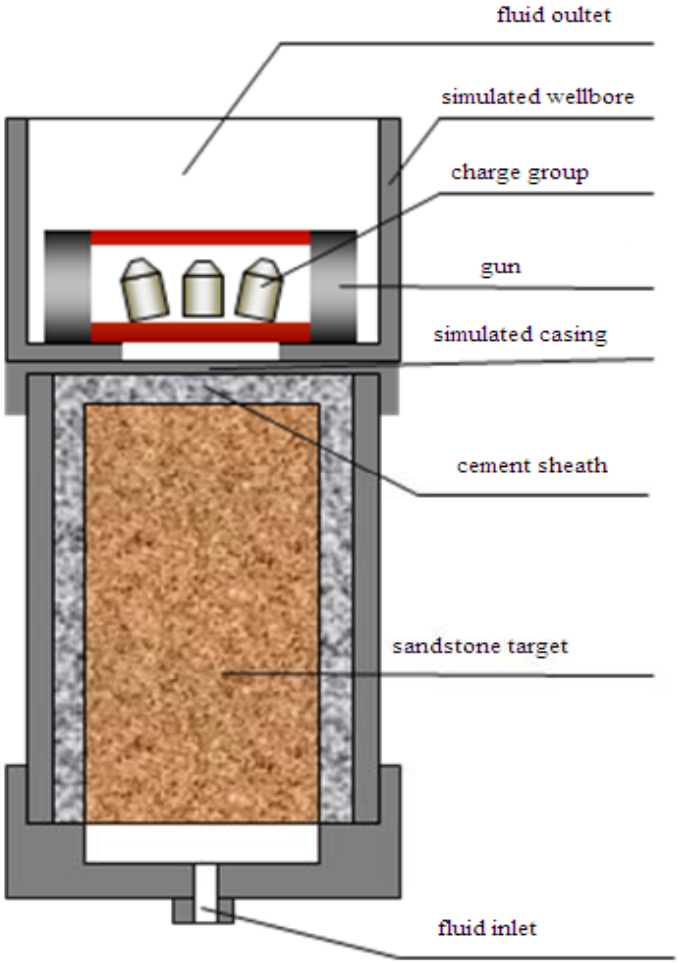
3. Laboratory Tests

Surface Test of Berea Sandstone Target

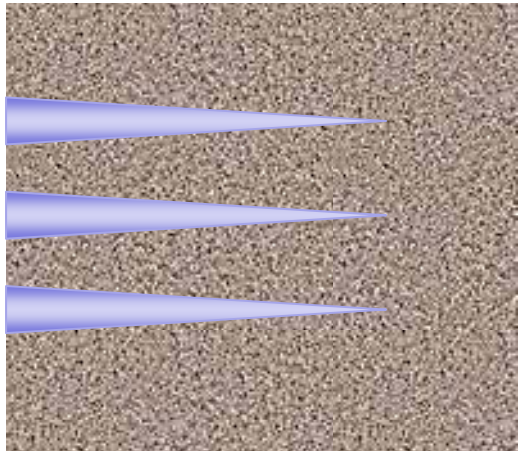
The tests were conducted using 370mm diameter Berea sandstone cores by 680mm long, average porosity of 20 percent, and average permeability of 127 mD, with kerosene as the flow media.



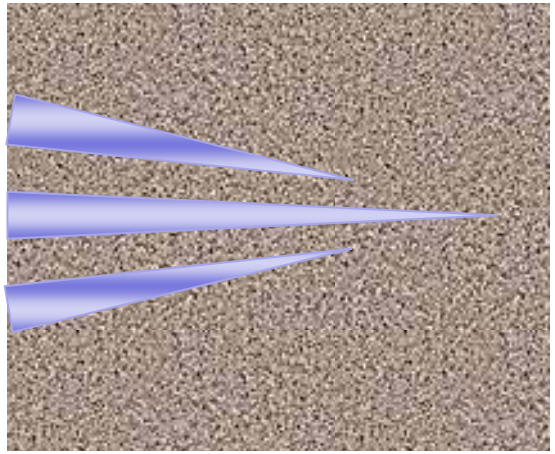
3. Laboratory Tests

Surface Test of Berea Sandstone Target

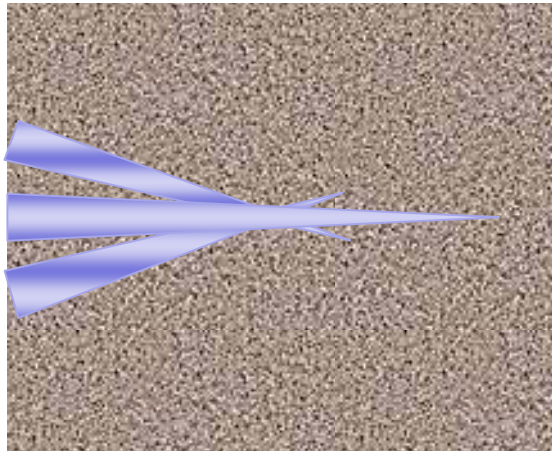
At the same conditions, three kinds of triple-jet tests were conducted, the first using three conventional parallel charges, the other two tests using angularly focused charges. Both perforating tests with angularly focused charges showed increased penetration, tunnel volume and flow performance. The penetration increase measured was 17.9 percent, and flow performance increase measured was 19 percent.



Parallel perforating(T1)



Angular perforating test 1 (T2)



Angular perforating test 2 (T3)

3. Laboratory Tests

Surface Test of Berea Sandstone Target

Test number	Sandstone target penetration (mm)	Tunnel volume(cm^3)
T2 (Angularly focused 1)	280	69
T3 (Angularly focused 2)	260	61
Average value	270	65
T1 (Parallel)	230	53
Performance improvement	17.39%	22.64%

The penetration in sandstone is increased by 17.39 percent, and the tunnel volume is increased by 22.64 percent.

3. Laboratory Tests

Concrete Target Test

Purpose

Based on the characteristics of the perforating, the surface concrete tests are needed to verify whether it can meet the industry standards, and provide basis for the field tests.

Test Conditions

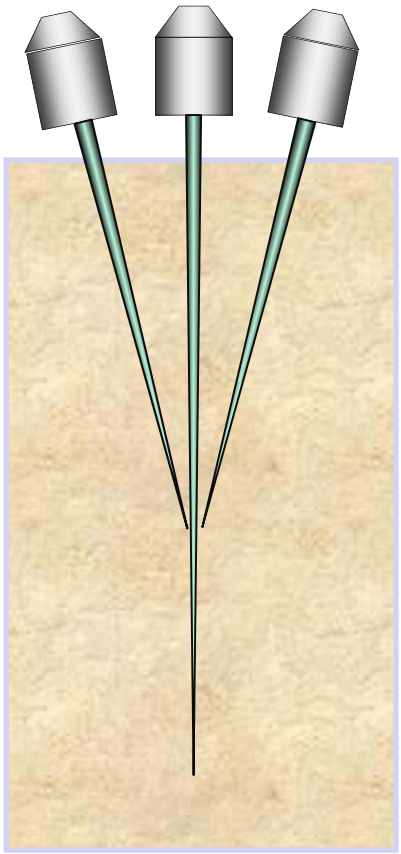
The tests were conducted using a 2.5m diameter concrete target, 1m long gun, 15 charges, 3 charges/set. The normal penetration depth of main conventional perforating charges is 860mm; and the upper and lower charges is 620mm.

Results

The average penetration of the main tunnel was 1222mm, and the upper and lower tunnel was 611mm. The average diameter of the main tunnel was 11.2mm, and the upper and lower tunnel was 14.2mm. There was no cracks and fall off on the gun bodies, which reaches the industry standards. And the tunnels meet the technical requirements.

3. Laboratory Tests

Concrete Target Test



Concrete Test Report

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射孔器地面穿混凝土靶试验结果报告单

试验编号 WSK041-2012(Q)　　试验日期 2012-11-30

射孔弹型号 GH45RDX39-1/DP44RDX39-5　　生产厂家 大庆射孔弹厂

射孔枪型号 102-15-72-70　　生产厂家 大庆中油红祥寓油田科技开发有限公司

装弹数量 15 发　　有无盲孔 有

混凝土靶强度 58.9 MPa　　靶规格 Φ2500mm×1400mm

靶龄 207 d　　套管规格及钢级 Φ177.8mm×11.51mm, L80

样品编号:WSK103-2012(Q)　　填报日期：2012-12-05

序号	检测参数		试验结果(L)
1	穿孔深度 mm	主孔道	$\bar{X}$=1222　S=93
		辅助孔道	$\bar{X}$=611　S=97
2	穿孔孔径 mm	主孔道	$\bar{X}$=11.2　S=0.5
		辅助孔道	$\bar{X}$=14.2　S=1.0
3	最大内毛刺高度 mm		3.5
4	射孔枪上孔眼处单侧裂纹 mm		0
5	射孔枪横向裂纹，枪头、枪尾脱落情况		无裂纹　无脱落
6	盲孔对位率 %		100
备注	检测说明： 1、主孔道装弹型号为:DP44RDX39-5;辅助孔道装弹型号为：GH45RDX39-1		

3. Laboratory Tests

Concrete Target Test

Triple-jet gun

Concrete target test

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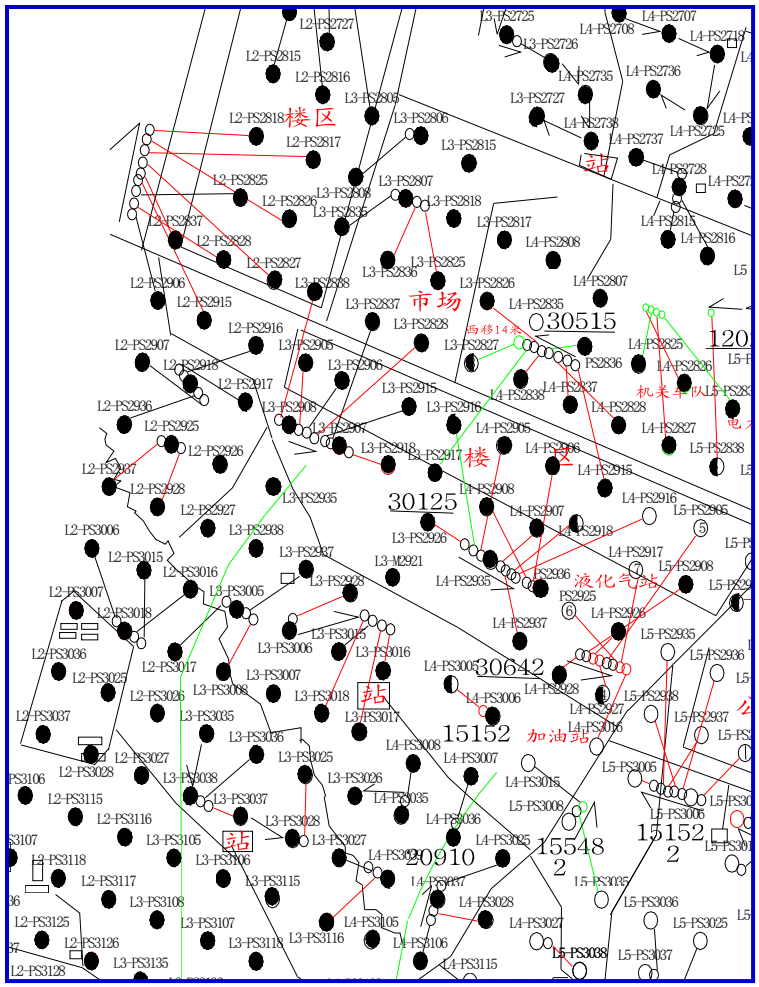
4. Field Applications

We chose two blocks in Daqing Oilfield to verify the triple-jet perforating results. The average effective permeability of the first block is 490mD, and 20 wells were selected. The average effective permeability of the second block is 517mD, and 9 injection wells were selected. Also the comparative and neighboring production and injection wells were chosen to compare the results.



4. Field Applications

Results

Result comparison of production wells

Perforating method	Number of wells	Averg. perforating thickness（m）	Averg. fluid production per day（m3/d）	Averg. fluid productivity（m3/d.m）	Increment（%）
Conventional perforating	23	5.89	4.59	0.78	16.7
Triple-jet perforating	20	4.98	4.65	0.91	

Result comparison of injection wells

Perforating method	Number of wells	Averg. perforating thickness（m）	Averg. Injection rate per day（m3/d）	Averg. injectivity（m3/d.m）	Increment（%）
Conventional perforating	12	6.49	32.2	4.96	17.7
Triple-jet perforating	9	5.86	34.2	5.84	

The average fluid productivity is increased by 16.7 percent

The average injectivity is increased by 17.7 percent

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5. Conslusions

- After researches and designs, the delayed detonating technology of perforating charges is developed, which accurately control the detonation time, and eliminate the interference between three charge sets. The charge jackets of anti-interferance and the triple-jet perforator with 5 phases, phase angle 144º, 5 sets/m, and 15 shots/m are developed.
- Through laboratory tests of the triple-jet perforating, and compared with conventional perforating, the penetration is increased by 17.39 percent, the tunnel volume is increased by 22.46%, and the flow efficiency is increased by 19 percent.
- Through tracking the application results of the triple-jet perforating, and compared with the results using conventional perforating in the same block under the same geological conditions, the average fluid productivity of producing wells is increased by 16.7 percent, the average injectivity of the injection wells is increased by 17.7 percent, which has obtained very good results.

Thank you!