Clustered perforation technology

Science & Technology Management Department, CNPC
Clustered Perforation

— To realize conventional production of unconventional oil and gas!
China National Petroleum Corporation (abbreviated to CNPC) is a state-authorized investment institution, a state-controlled company and a comprehensive transregional, trans-trading and transnational petroleum company integrating upstream and downstream production, national and foreign trade, production and marketing and operating based on the modern enterprise system. The main business of CNPC covers oil and gas business, petroleum engineering services, petroleum engineering construction, petroleum equipment manufacturing, financial services, new energy development, etc. The domestic and foreign oil and gas production equivalent of CNPC was 0.26 billion tons in 2015, the crude oil processing capacity 0.196 billion tons, the product oil sales volume 0.174 billion tons, and the natural gas sales volume 129.0 billion cubic meters.

CNPC ranked third among the 50 large petroleum companies worldwide according to Petroleum Intelligence Weekly and fourth among the 500 large companies globally according to Fortune in 2015.
CNPC carries out the resource, market and internationalization strategy, sticks to the science and technology development idea “main business strategy drive, development objective orientation and top-layer design” and the guideline “self-innovation, key crossing, support to development and guide to future”, continuously promotes science and technology advance, increases science and technology innovation capacity and has obtained a large number of advanced practical technologies with independent intellectual property rights taking national key special science and technology projects as the head, the Company’s key special science and technology projects as the core, key field tests as the grasp and key equipment, software, products and standards as carriers.

Clustered perforation technology is one of representative significant innovative achievements.
The principle of the clustered perforation technology: the perforation string and bridge plug are run to the target formation on the premise of effective connection of well bore with formation using the cable conveyed mode according to the pumping design procedure; 20 stage ignition operations can be realized within one round trip. The clustered perforation technology realizes combined bridge plug setting and multi-cluster perforation, creates hole conditions for staged fracturing and is the best choice for development of unconventional oil and gas resources.

CNPC has independently developed the clustered perforation technology, including four sets of tools and technologies such as readily drillable composite material bridge plug staged system, high pressure dynamic seal cable blowout prevention system, etc. and three sets of software and technologies such as clustered perforation selective control software, pumping procedure design optimization software, etc. The clustered perforation technology creates clean and high-conductivity perforation channels for hydraulic staged fracturing of unconventional reservoirs and controls initiation and extension of fractures. The technology belongs to a domestic pioneered technology and reaches the international advanced level integrally.

The clustered perforation technology has now been popularized and applied for over 300 wells-times in over ten oil and gas blocks including three national shale gas demonstration areas such as Weiyuan-Changning, Jiaoshiba and Zhaotong, Shell Jinqiu-Fushun block, South Jiangsu block of Total, etc. With the technology, the operation success rate is 100%, the cost is reduced by 30%, and the efficiency is increased by over 200%. The technology has created multiple domestic perforation records. The technology’s advantages such as high-safety, high-efficiency and low-cost provide a powerful technical support to the development of unconventional oil and gas resources.
The readily drillable composite material bridge plug system consists of readily drillable composite material bridge plug and bridge plug setting tool. The composite bridge plug is set by the bridge plug setting tool, thus temporarily plugging reservoirs and providing favorable conditions for subsequent fracturing. After fracturing completion, the readily drillable composite material bridge plug is drilled away using coiled tubing or tubing in general.

2.1 Readily drillable composite material bridge plus staged system

1. Readily drillable bridge plug

The bridge plug is designed with a special structure and manufactured of composite material which has good drillability, and can be provided with or without production passages. The bridge plug is resistant to 70MPa differential pressure and 150°C temperature, and can temporarily plug each section of formations.

2. Bridge plug setting tool

The composite bridge plug is set at the downhole preset position through the relative motion between the internal piston and mandrel. The setting tool is applicable to various types of casing and deep well operations and has advantages such as high setting success rate and high timeliness.

3. Combined bridge plug and perforation technology

The string is cable-conveyed in hole at a time, where the bridge plug can be set once and the perforation operation of not more than clusters can be completed. The technology has advantages such as simple operation and high success ratio.
2.2 Clustered selective perforation system

The clustered selective perforation system mainly consists of selective perforator and multi-stage ignition controller and is an operation system which can achieve multiple times of perforations within one round trip under the control by the multi-stage ignition controller. The system uses digital encoding, downhole addressing and whole-process monitoring technologies, can achieve real-time detection and intelligent shooting under the control by the selective software.

1. Selective perforator

The selective perforator uses a special gun body structure, wiring mode and connection mode and achieves selective perforation and intelligent shooting via the surface control system.

1) Conventional selective perforator

Each stage of perforator has independent sealing property, and is controlled by an independent ignition controller which can achieve selective perforation.

2) Orientable selective perforator

The orientable selective perforator uses the special internal orientation mode with the gun carrier rotated, has advantages such as reliable orientation and high accuracy, and can realize orientable selective perforation and 360° all-around perforation.

3) Constant surface selective perforator

The perforator uses a special perforating charge layout mode. With the perforator, 3 perforation holes can be formed on the inner wall circumference in the same cross section vertical to the casing’s axial direction. By changing the in-situ stress distribution in the same cross section in well bore, stress concentration belts are formed inductively in perforation holes, thus effectively controlling the strike direction of fractured fractures and achieving the best stimulation effect.
2. Multi-stage ignition controller

The multi-stage ignition controller is used to control each stage of perforator and is a detection and initiating control device with selectivity and correspondence.

1) Mechanical multi-stage ignition controller

The controller uses the alternately positive and negative ignition technology to excite perforators successively. The controller is resistant to 204°C temperature and 140MPa pressure.

2) Electronic multi-stage ignition controller

The controller realizes real time monitoring through software control and has selective excitation function. The controller is resistant to 150°C temperature and 140MPa pressure.
2.3 **Horizontal well pumping system**

The horizontal well pumping system is fitted with flexible weighting device, electromechanical releasing device, matching tools, etc., and can increase the string’s capacity of passing in high-inclination wells and horizontal wells, its treatment capacity in an emergency.

![Structure schematic of horizontal well pumping system](image)

1. **Flexible weighting device**

   The device uses flexible connection mode to connect the downhole string without hindering free rotation of the downhole string, and can increase the string’s capacity of passing in the build-up sections of high-inclination wells and horizontal wells.

2. **Mechanical releasing device**

   When the downhole string encounters emergencies such as blockage etc., it can be released through surface control. The device has advantages such as quick releasing and high safety and reliability and can effectively protect downhole tools and cables. After releasing, the fish head is reserved for convenience of subsequent fishing operation.

3. **Matching tools**

   1) Special fishing tool

   The tool has a special gripping and clamping structure and is conveyed via coiled tubing or tubing to the fishing head position of the fish top to fish the downhole fish. The tool has advantages such as simple and convenient operation, operation time reduction and high fishing success rate.

   2) Pumping sub

   The sub is designed with special diversion grooves and conical chamfers to increase the cross section flow rate of the pumped well fluids and the string’s capacity of passing downhole.
3) Friction reducing device

The device is designed with built-in roll balls or rollers to reduce the string’s friction resistance in wells and its capacity of passing downhole.

2.4 High pressure dynamic seal cable blowout prevention system

The high pressure dynamic seal cable blowout prevention system is a dynamic seal blowout prevention system composed of special cable, cable BOP, catcher (anti-falling device), lubricator, gripping and clamping device, cable blowout prevention control head, grease injection control device, etc.

Structure schematic of high pressure dynamic seal cable blowout prevention system

1. Wellhead blowout prevention equipment

The wellhead blowout prevention equipment has well sealing functions such as cable sealing, blind and ram sealing and cable shearing-off and can realize (negative pressure) perforation operation and dynamic sealing at high pressure and effectively prevent blowout accidents. The wellhead blowout prevention equipment is operated simply and conveniently and can respond quickly in an emergency. Its applicable drift diameter range is 76~160mm and it can be resistant to maximum pressure 105MPa.
2. Special cable

Φ 8mm special cable is used in clustered perforation. The cable has large tensile strength, high bending performance, good wearability, high resistance to water and corrosion, and high performance at high pressure.
2.5 Clustered perforation selective control software

The software realizes digital encoding, downhole addressing, intelligent selective shooting and whole-process monitoring of perforators. The software can be used to selectively shoot each stage of perforating gun or set each stage of bridge plug through micro-current detection and independent addressing, thereby completing the whole clustered perforation operation process. The software has advantages such as good functionality, stable running and simple and convenient operation.

2.6 Pumping procedure and design optimization software

The pumping procedure design and string optimization software has been developed in response to the relevant influential factors such as string structure in wells, string length design, string stress, well bore curvature, pumped fluid parameter, friction resistance coefficient, etc. The established calculation model is scientific and reasonable, the optimization design result provides very good guidance to operations.
CNPC Chuanqing Drilling Engineering Company Limited has integrated clustered perforation technology service capacity involving operation design, tool manufacturing, operation service and field technical support. The clustered perforation technology has now been applied for over 300 wells-times in 4 reservoirs, 3 national shale gas demonstration areas, 3 cooperative blocks, 4 oil and gas fields and 5 oil and gas blocks of SINOPEC, 4 oil and gas fields and 8 oil and gas blocks of CNPC. With the technology, the operation success rate is up to 100%. The technology has reduced operation cost and improved operation efficiency.

### Application areas of clustered perforation technology

<table>
<thead>
<tr>
<th>Scope of application</th>
<th>Specific area</th>
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<tbody>
<tr>
<td>4 types of reservoirs</td>
<td>Shale gas, tight oil, tight oil, CBM</td>
</tr>
<tr>
<td>3 national shale gas demonstration areas</td>
<td>Fuling Jiaoshiba, Weiyuan—Changning, Zhaotong</td>
</tr>
<tr>
<td>3 cooperative blocks</td>
<td>Shell Jinqiu—Fushun, Total South Jiangsu, EOG Bajiaochang oil and gas block</td>
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</tbody>
</table>
| 4 oilfields and 5 oil and gas blocks of SINOPEC | (1) Jianghan oilfield: Fuling Jiaoshiba oil and gas block  
(2) Huabei oilfield: Honghe and Jinghe oil and gas block  
(3) Southwest oilfield: Xinchang oil and gas block  
(4) Jiangsu oilfield: Zhangjiaduo oil and gas block |
| 4 oilfields and 8 oil and gas blocks of CNPC | (1) Southwest oil and gas field: Weiyuan-Changning, Anyue, Hechuang, Gongshanmiao and Longgang Longqian oil and gas blocks  
(2) Zhejiang oilfield: Zhaotong oil and gas block  
(3) Changqing oilfield: Sulige oil and gas block  
(4) Tuha oilfield: Santanghu oil and gas block |
Well W201 is the first shale gas well in China. The well is a vertical well. It was spudded at the end of 2009, with the total depth of 2840m. The clustered perforation technology (two-stage perforation) was firstly used in perforation completion operation of the shale gas well in China. Successful development of well W201 opened the prelude of shale gas development in China.

Well JY12-4HF is a shale gas horizontal well located at Jiaoshi Town, Fuling District, Chongqing, with the total depth of 4720m. The clustered perforation technology in combination with 89-model perforating guns and Xianfeng perforating charges was used to complete 25 intervals of cable operations and “69 clusters of perforation and 25 bridge plugs” operations in the 2099m horizontal section of this well in Jan. 2014. With the clustered perforation technology, the well created three domestic records involving the longest horizontal well section of clustered perforation, the largest number of perforation intervals and the largest number of clusters in a single well using the clustered perforation technology.

CNH2 well cluster consists of 4 wells such as...
CNH2-1, CNH2-2, CNH2-3 and CNH2-4, with their average depth being about 3710m and their horizontal section length range being 967~1360m. The “pairing” mode for every two wells was used in operation of the well cluster; that is, at the same time of perforation operation in two wells, the other two wells were fractured, and perforation and fracturing operations were performed alternately and continuously in two pairs of wells. Perforation operation in totally 48 intervals and 141 clusters were completed and 44 bridge plugs were set within continuous 10 days, and “synchronous zip type” factorial clustered perforation operation was realized in China for the first time.

The HTHP (High Temperature and High Pressure) test equipment consists of ultra-high pressure vessel,
three main systems (ultra-high pressure system, pressure stabilizing system, and heat conducting oil heating and circulating system), two auxiliary systems (cooling water system and compressed air system) and measuring and controlling system. The maximum operating temperature is 210°C, and maximum operating pressure of the equipment is 200MPa respectively. With the HTHP test equipment, the performance variation law of perforating charges, perforating guns and matching downhole tools at high temperature and high pressure can be understood accurately, thus providing effective test means for developing high performance perforation equipment.
The laboratory has high precision laser particle size analysis instruments and can test metal powder materials, thus greatly improving the automation degree and precision of particle size measurement. The laboratory has the independently developed “Numerical simulation and evaluation system for petroleum perforating charges—Perfjet V1.0” program. It can realize test simulation analysis of perforating charges, predict test results, show the data and images of explosion and perforation process of perforating charges in detail, achieve the development of new perforating charge products and technical improvement of the existing products, and reduce the development period, test times and test funds.
CNPC Chuanqing Drilling Engineering Company Limited has obtained API Specification Q1 certificate and ISO 9001:2000 quality management system certificate. The Company manages the whole production and service process strictly according to the requirements of API Q1 quality system. The products meet the requirements of GB/T20489—2006 General Technical Conditions for Shaped Charge Perforators for Oil and Gas Wells.
The Company formulated 1 enterprise standard for clustered perforation technology—Technical Specification for Sand Fracturing of Shale Gas Reservoirs Part 5: Clustered Perforation Technology (Q/SYCQZ 688.5—2013). The standard specifies the operation conditions, operation design, field operation, HSE requirements, etc. in clustered perforation operation.
CNPC Chuanqing Drilling Engineering Company Limited applied for and obtained 20 patents of the clustered perforation technology, including 7 invention patents and 13 licensed utility model patents. This reflects that the clustered perforation technology of the Company takes the lead in the completion perforation field of unconventional reservoirs.

**Patents of clustered perforation technology**

<table>
<thead>
<tr>
<th>Patent name</th>
<th>Patent No./application No.</th>
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<tbody>
<tr>
<td>A downhole ignition control device</td>
<td>ZL201120211699.8</td>
</tr>
<tr>
<td>A flexible weighting device for cable perforation</td>
<td>ZL201120211689.4</td>
</tr>
<tr>
<td>A downhole two-ignition perforation system</td>
<td>ZL201120211687.0</td>
</tr>
<tr>
<td>An intermediate joint device for multi-stage ignition perforation</td>
<td>ZL201320578683.X</td>
</tr>
<tr>
<td>An inter-stage isolation device for multi-stage ignition perforation</td>
<td>ZL201320578830.3</td>
</tr>
<tr>
<td>A bypass wiring device for multi-stage ignition perforation</td>
<td>ZL201320578745.7</td>
</tr>
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<tr>
<td>A modular sabot device</td>
<td>ZL201320601066.7</td>
</tr>
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<td>A constant surface perforation modular sabot for oil and gas wells</td>
<td>ZL201320583673.5</td>
</tr>
<tr>
<td>A modular sabot constant surface perforator for oil and gas wells</td>
<td>ZL201320583672.0</td>
</tr>
<tr>
<td>A directional steel structure</td>
<td>ZL201320583672.0</td>
</tr>
<tr>
<td>A downhole electric detonator ignition control circuit for perforation</td>
<td>ZL201320753463.6</td>
</tr>
<tr>
<td>A signal detection and processing circuit for perforation ignition control circuit</td>
<td>ZL201320753724.4</td>
</tr>
<tr>
<td>A wide-range input stabilized voltage supply circuit for downhole perforation ignition control circuit</td>
<td>ZL201320753726.3</td>
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<tr>
<td>An intermediate joint device for multi-stage ignition perforation</td>
<td>201310426734.1 (invention)</td>
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<td>201310431399.4 (invention)</td>
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<tr>
<td>A modular sabot constant surface perforator for oil and gas wells</td>
<td>201310431108.1 (invention)</td>
</tr>
<tr>
<td>A modular sabot device</td>
<td>201310447859.2 (invention)</td>
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</table>
Wu Mingde  
Professor level senior engineer, expert enjoys the government special allowance. He once participated in the study of perforation technology for China’s first 6000m ultra-deep well and organized comprehensive technical transformation of Sichuan Perforating Charge Plant, perforating charge manufacturing technology introduction and comprehensive improvement of perforation operation technology. Multiple perforation technology papers written by him have been published. He has made positive efforts to promote the industrialization of clustered perforation technology.  
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Chen Feng  
Technical expert, winner of “Sun Yueqi Energy Science and Technology Youth Award”. He took charge of completing multiple fundamental research projects and new practical technology research projects such as “research on integration and application of new composite perforation technologies”, “research on staged and clustered perforation technology and industrial application of a complete set of equipment”, etc. He took charge of working out the implementation scheme for the special perforation topic of the national special key logging project. He has obtained multiple provincial and ministerial prizes and patents.  
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Technical expert. He took charge of completing multiple fundamental research projects and product development projects such as “development of ultra-deep penetration perforating charges”, “development of high temperature perforating charges”, “research on calculation method and calculation software for perforating charges for oil and gas wells”, “development of perforating charges with high hole density and large hole diameter”, etc. He has obtained multiple provincial and ministerial prizes and patents.
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Tang Kai

Technical expert. Winner of “Sun Yueqi Energy Science and Technology Youth Award”. He has successively taken charge of and participated in the research on over 40 scientific research projects such as “research on ultra-positive pressure perforation technology”, “clustered perforation technology for shale gas reservoirs”, etc. as well as clustered perforation scheme design and field technical support to over 10 oil and gas blocks including 3 national shale gas demonstration areas, reserve contract blocks, etc. He has obtained multiple provincial and ministerial prizes and patents. He took charge of formulating 1 industrial standard for clustered perforation and 2 enterprise standards.
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Wang Hai
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CNPC Chuanqing Drilling Engineering Company Limited focuses on the study and application of perforation technologies and promotes normalized operation of unconventional clustered perforation means. The Company has established a clustered perforation tool manufacturing center and professional perforation service teams. The Company is fitted with complete series of clustered perforation equipment and provides “integrated” services involving optimization design, equipment manufacturing and operation.

The professional perforation technology research and development center has developed a large number of high and new technologies and products including clustered perforation technology, which occupy China’s middle to high end perforation market, enjoy great popularity from oilfield customers, and are the foundation for research and development of domestic first-class perforation technologies.

Equipment manufacturing: the Company has now built up a powder metallurgy shaped charge cover production line and a perforating charge production line which reach the domestic advanced level. The Company has an advanced perforating gun and matching product production line and the production capacity of 2 million perforating charges and 200000m perforating guns per year. The manufactured equipment and tools have been favorably appraised in the oilfield markets including Southwest oil and gas field, Zhejiang oilfield, Changqing oilfield, Tuha oilfield, Shell Jinqiu, Total South Jiangsu, etc.
Operation teams: the Company has 32 digital perforation teams including 7 class A ones and 25 class B ones, which provide services mainly in the oilfield markets including Sichuan-Chongqing, Tarim, Tahe, Qinghai, North Shaanxi, Sulige, Shandong Linpan, Jidong, etc. and keep long-term cooperation relationship with domestic and foreign large oil companies such as CNPC, SINOPEC, Shell, Total, EOG, etc.

7.2 Training

The Company has a professional expert technology team and manuals and training courseware on experiment and test technologies, equipment, field operation, safety technology, etc. According to the different needs of users, the Company works out a detailed training plan and provides whole-process clustered perforation technology training services.

7.3 After-sale services

The Company has established a perfect after-sales service system. The Company has professional technical personnel “on-call” round the clock, can provide remote technical support and solve technical problems effectively in time, and tracks and records the user’s after-sales service demand till meeting the user’s demand.

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