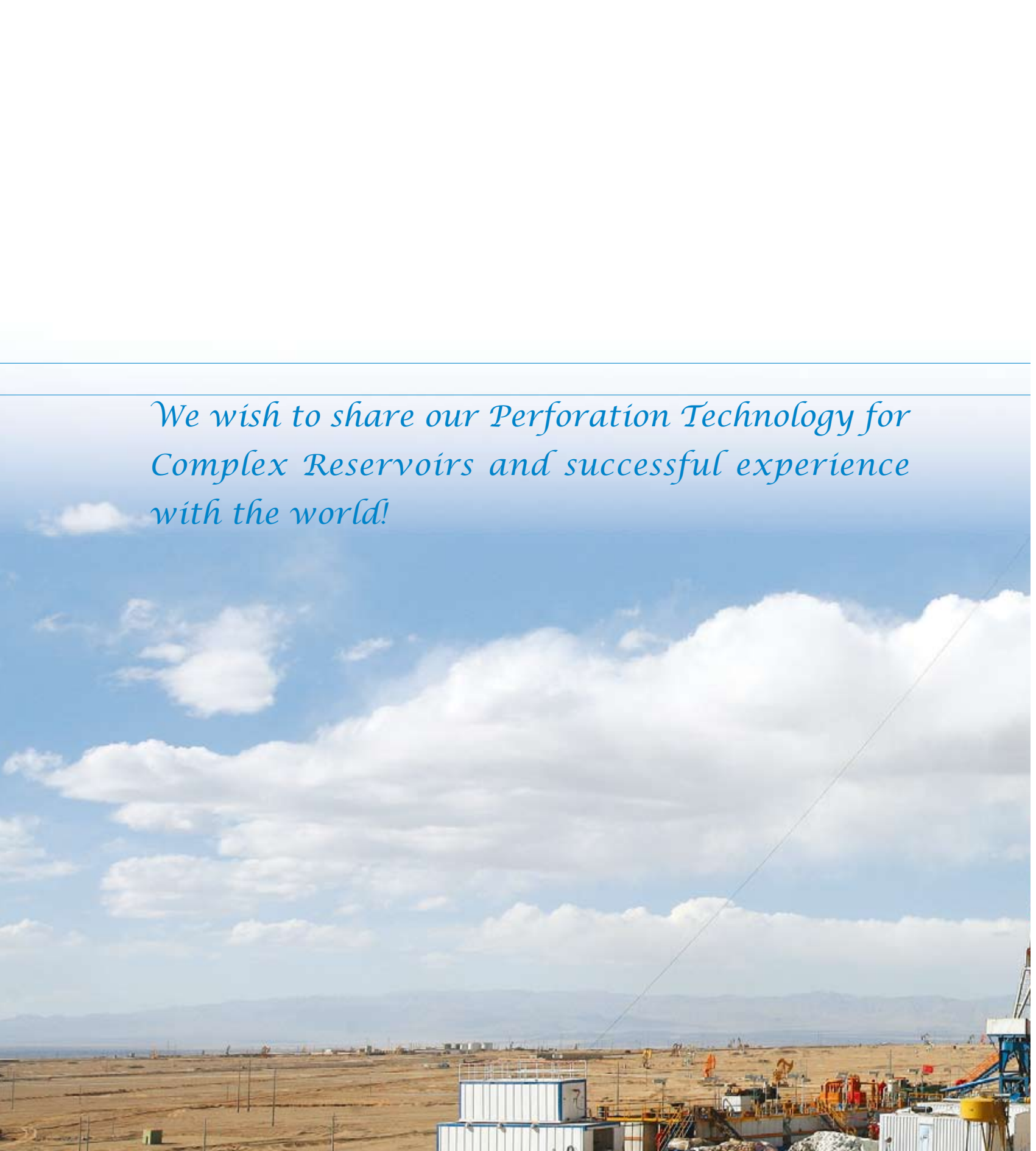
Perforation Technology for Complex Reservoirs

Science & Technology Management Department

2011

CHINA NATIONAL PETROLEUM CORPORATION

We wish to share our Perforation Technology for Complex Reservoirs and successful experience with the world!



Contents

China National Petroleum Corporation (CNPC) is a state-authorized investment agency and a state holding company. As an integrated oil company of cross-regions, cross-industries and cross-countries, it adopts modern enterprise system to realize the integration of upstream and downstream operations, internal and external trade and production and marketing. CNPC has 17 upstream companies, 33 downstream companies and 36 large-scale marketing companies. It is China's largest producer and supplier of oil and gas, and also one of the largest refined oil products and petrochemicals. In 2010 CNPC produced 105 million tons of crude oil and 72.5 billion cubic meters of natural gas, while crude processing volume reached 135 million tons. The total revenue of RMB1,720 billion with a profit of RMB172.7 billion had been achieved the same year. Its profit is among the highest of the domestic enterprises in China.

CNPC was ranked 10th in Fortune Global 500 in 2010 and 5th among global top 50 oil companies.

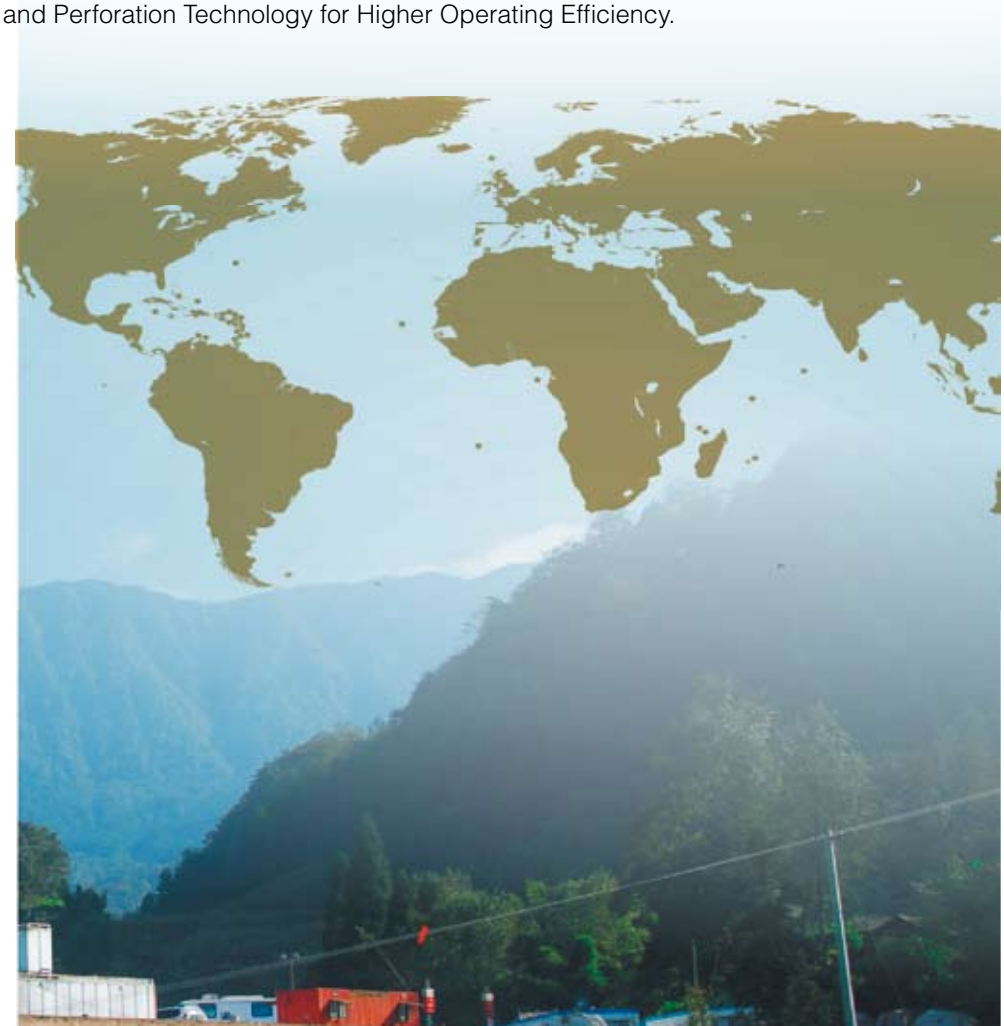
CNPC strictly follows by the combined strategies of increasing resource capacity, expanding market shares and consolidating the international role, and persists in regarding technical innovation as a key framework to advance technological progress. To develop its core businesses, focuses will be placed on the solutions of key bottleneck technologies and key proprietary technologies. Thanks to continuously improving of the technical innovation system, optimizing the configuration of technological resources and strengthening the construction of strong talent teams, CNPC's technological creativity has been considerably upgraded. Consequently, a large number of technologies have been developed independently, with its own intellectual property.

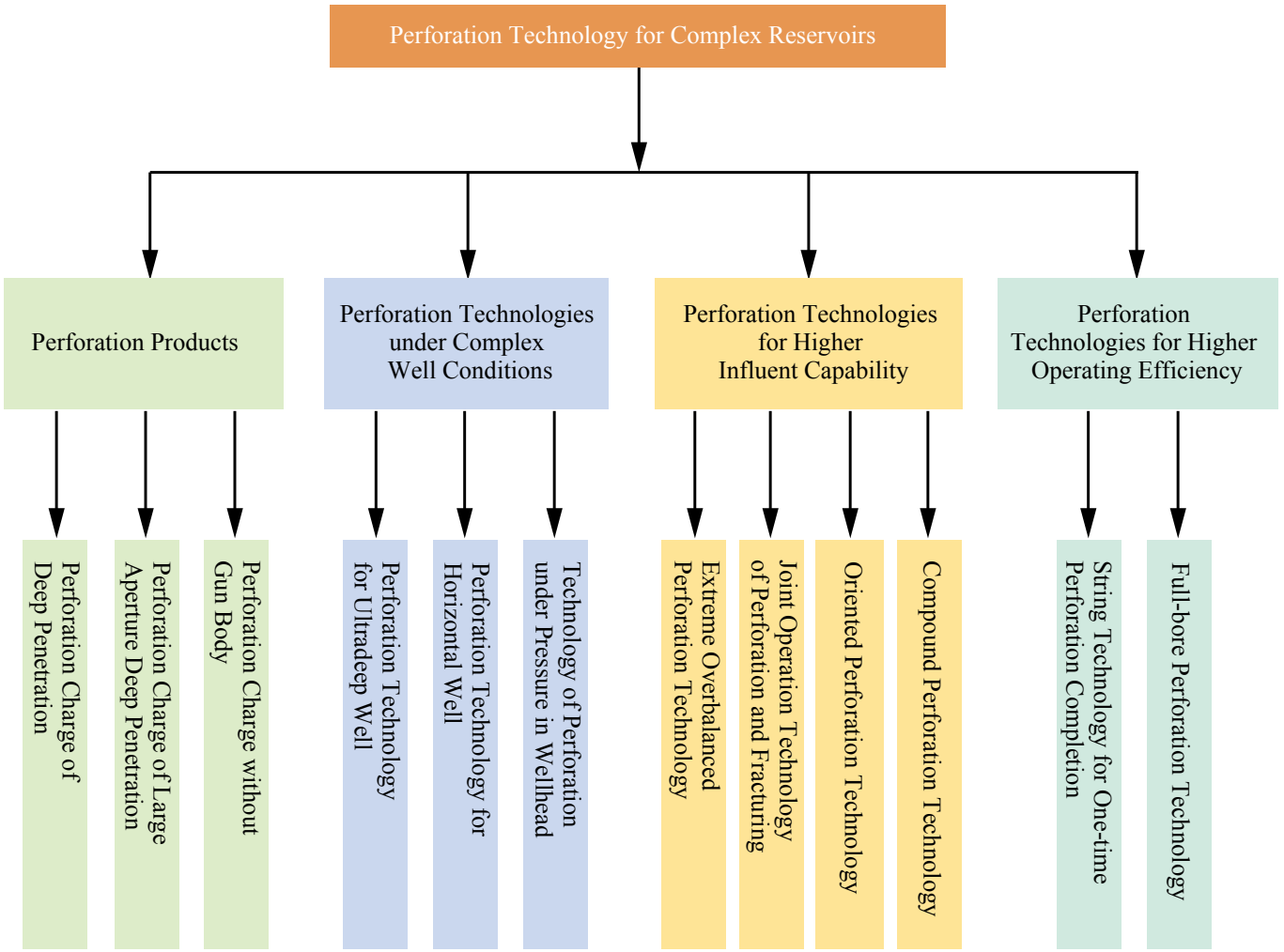
The Perforation Technology for Complex Reservoirs is one of representatives for major innovations of CNPC.

1 INTRODUCTION

CNPC has been taking up with the research and development of perforation products and research of perforation engineering. CNPC has established specialized organizations for the production of perforation charge, design and manufacture of casing perforation tools, perforation technology and casing perforation services. It owns the internationally advanced manufacturing equipment and techniques for perforation charge. The perforation construction service and equipment are marketed to countries and regions such as India, Thailand, Iran, Kazakhstan, Turkmenistan, Sudan, Australia and Southeast Asia, etc.

CNPC has independently researched and developed four series including 12 unique technologies and products for Perforation Technology for Complex Reservoirs. The four series are Complement Perforation Products, Perforation Technology under Complex Well Conditions, Perforation Technology for Higher Influent Capability and Perforation Technology for Higher Operating Efficiency.





● 4 Series of Technologies

● 12 Unique Technologies and Products

2 Unique Technologies

1. Perforation Product & Technologies

1.1 Manufacturing Technology of Perforation Charge

For the perforation charge being praised as the "golden key" for opening the gate of oil reservoirs, its perforating performance is one of the important factors that affect the deliverability of oil and gas wells. CNPC, facing the complex targets of exploration and development as well as various oil reservoir types, has strengthened the research and development of the perforation charge technology, and developed more than 100 sizes of perforation charges that apply the unique technologies including Perforation Charge of Deep Penetration, Perforation Charge of Large Aperture Deep Penetration, Perforation Charge without Gun Body, etc. These unique products can generate porous channels being deep, regular, carrotless and less detrimental to the formations, thus providing the material guarantee for the development of highly-efficient complex reservoirs.

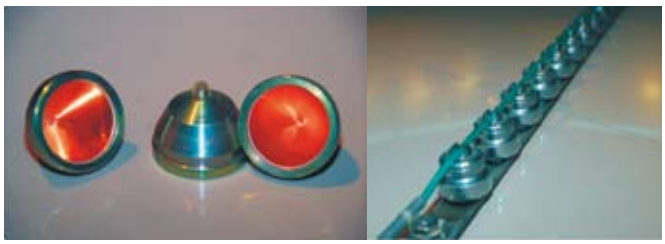
1.2 Perforation Charge of Deep Penetration (proprietary technology)

The Perforation Charge of Deep Penetration, with its perforation charge aimed at the maximum perforation depth and with its unique structural design, makes the exploded perforation charge generate a stream of jet with stability, compactness and high extensibility and form longer perforation depth in the formation. The salient features of Perforation Charge of Deep Penetration are the long perforation depth, the maximum perforation depth of 60.58", the regular porous channels that are formed and small damage to the formation. Moreover, it could greatly run through the formation's contaminated zone and produce favorable wellbore conditions for stimulation treatments such as continuous fracture acidizing. It is fit for the perforating operation of reservoirs with low porosity, low permeability, low abundance and high density.

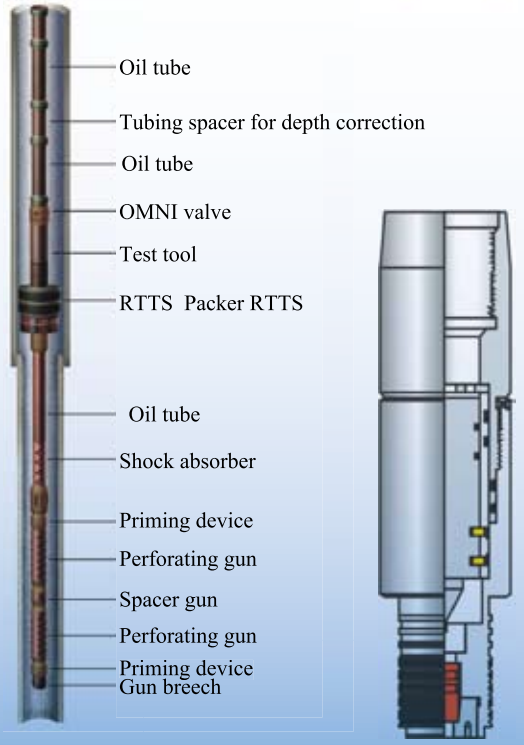
1.3 Perforation Charge of Large Aperture and Deep Penetration (proprietary technology)

The Perforation Charge of Large Aperture and Deep Penetration refers to the perforation charge that after explosion forms a hole of diameter being more than 0.55" and having longer penetration depth in the formation. Its salient features are that it increases the seepage area of the perforation channel, declines the formation's fracture pressure, and releases the drilling damage zone of the conventional reservoirs. Moreover, it has obvious effects on the production response of oil and gas for a single well, increases the single well production of reservoirs with low porosity and low permeability, and especially creates the best wellbore conditions for the implementation of technical measures of filling and sand control. It is fit for the perforating operations of heavy crude oil layers, loose oil layer, oil layer with sand production and wells with polymer injection.

1.4 Perforation Charge without Gun Body



The Perforation Charge without Gun Body refers to the perforation charge that does not use the perforating gun, only uses the elongated gun carrier to fix and connect the explosive fuse, being detonated with the priming device. The Perforation Charge without Gun Body adopts the single hermetically-sealed construction, has the features of high compression strength and high percentage of initiation rate, and meets the demands of the perforation operations under the conditions of high temperature and high pressure. Further, by adopting the Perforation Charge Technology of Deep Penetration, the explosion of the perforation charge, with strong penetration capacity, has less impact on the casing and gun carrier, etc., with the features of small volume, simple assembly, safe operation, etc. It is fit for the through-tubing perforation and perforation adding of oil wells with small opening.



2.Perforation Technologies under Complex Well Conditions

Aimed at the Perforation Completion Technology under Complex Well Conditions, the perforation technologies for ultradeep wells, horizontal wells and underbalanced wells, etc. are researched and developed. The technologies have features such as safety, reliability and high activity, and meet the need of protection, exploration and development of productive reservoirs. The technologies have been applied widely in CNPC's major fields and achieved the best effects.

2.1 Perforation Technology for Ultradeep Well

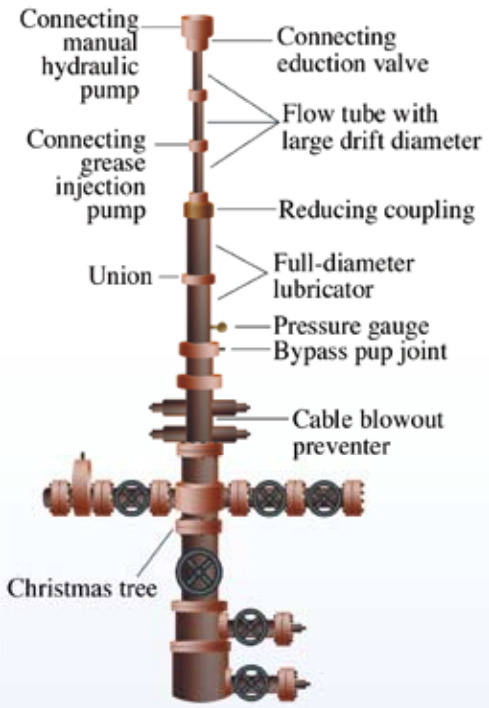
Perforation Technology for Ultradeep Well is fit for the oil and gas well with the depth of more than 18045ft. This technology overcomes bad well conditions of the ultradeep well, such as high temperature, high pressure, slim hole. The perforation of this technology can be conducted together with processes like acidification and testing, thus shortening the cycle of production test and reducing the cost and labor intensity. The technology is mainly fit for the oil and gas wells with the depth of over 19685ft. The technology has been applied successfully in 200 wells.

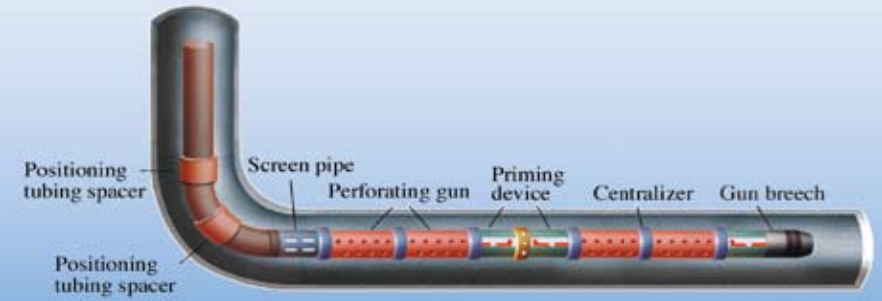
2.2 Perforation Technology for Horizontal Well

The Perforation Technology for Horizontal Well has been applied in more than 300 wells with 100% success rate, meets the need of the perforating completion operation for the horizontal well and provides powerful technical support for the industrial deployment of the horizontal well.

2.3 Technology of Perforation under Pressure in Wellhead

The technology is fit for the construction operation under balance and meets the need of the underbalanced perforation completion. In operation, it shall fit the cable blowout prevention system at the well mouth. The cable transports the casing perforation tool to the target formations under the dynamic sealing of the well mouth and carries out the perforation under pressure. This technology avoids the formation damages produced by the positive pressure perforating and increases the oil and gas production rate.





3. Perforation Technologies for Higher Influent Capability

For the development of reservoirs with low porosity and low permeability, its effect can usually be visible only after the stimulation treatments (e.g. fracture, acidizing, etc.) have been conducted. The Perforation Technologies for Higher Influent Capability includes four unique technologies, i.e. Extreme Overbalanced Perforation Technology, Joint Operation Technology of Perforation and Fracturing, Oriented Perforation Technology and Compound Perforation Technology, which provide technical support for improving the exploration and development of reservoirs with low porosity and low permeability.

3.1 Extreme Overbalanced Perforation Technology (proprietary technology)

The Extreme Overbalanced Perforation Technology is a new breakthrough for the perforating completion nowadays, which is applied widely in giant Chinese oil and gas fields.

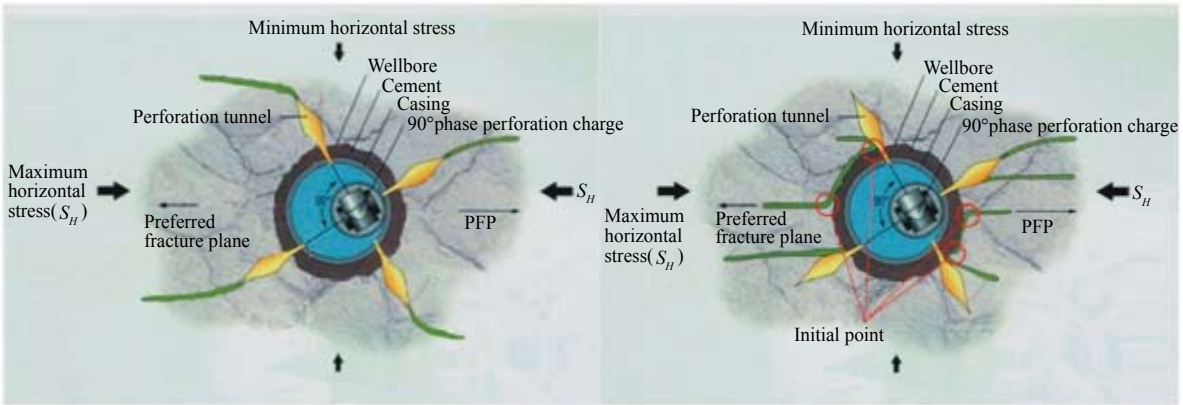
This technology overcomes the pollution of compaction generated by jet perforating. It can spread fractures, improve the effect of initial completion, shorten the cycle of production test and decline the cost of production tests.

The Extreme Overbalanced Perforation Technology is fit for the 3 kinds of conditions as below:

- Reservoirs, (e.g. Carbonatite, sandstone) with low porosity and low permeability
- Low reservoir pressure
- Reservoir with long-range drilling pollution
- The technology has 2 patented technologies:

A kind of pressure detonator with shear pin easy to be handled;

A kind of high density-pattern perforation gun used for oil and gas wells



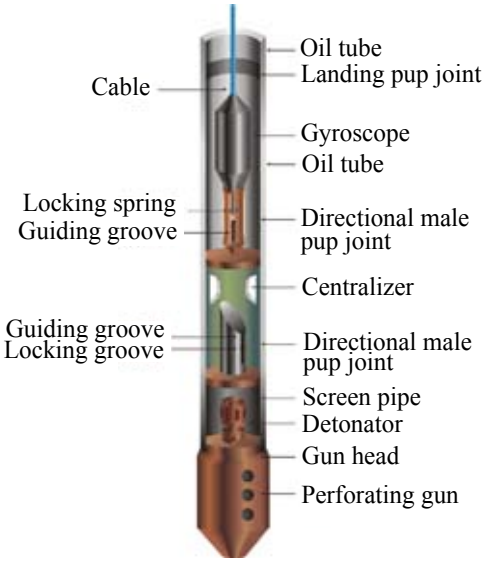
Fracture produced by extreme overbalanced perforation

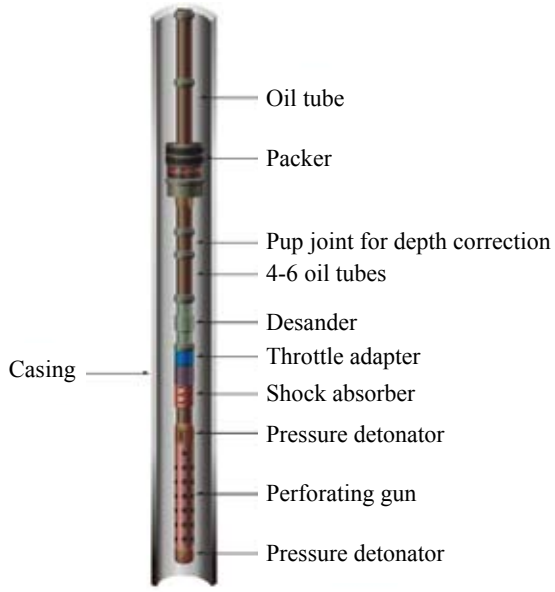
Fracture produced by common horizontal fracturing

3.2 Joint Operation Technology of Perforation and Fracturing

The Joint Operation Technology of Perforation and Fracturing can be applied with one pipe string. The technology can better solve the problems in packer setting and unsetting, and can generate the unimpeded passageways for acid or sand production, etc. The technology can also eliminate the potential for accidents during the operation, such as acidification being blocked, sand sealing or sanding in, etc. At present, CNPC has promoted this technology widely in giant oil and gas fields to reduce the cycle time of well testing and the expense of well testing.

This technology is granted with one patent, "A kind of automatic throwing-gun ignition device for perforating gun used for oil and gas wells". This proprietary technology ensures the completion of the automatic throwing-gun operation under high pressure, realizes continuous perforating, throwing gun and fracturing, saves time and operating cost, and protects the producing formation to a certain extent.





Combined pipe string with downward desander

3.3 Oriented Perforation Technology

The Oriented Perforation Technology, which perforates along the fracture azimuth and the direction of the maximum primary stress of the formation, can solve the problem of randomness in the conventional perforation and improve the effective rate of the perforating hole for fracturing oil and gas reservoirs. The technology has been applied in 50 wells on site and enhanced the oil and gas recovery rate.

3.4 Compound Perforation Technology

The technology utilizes the jet stream to ignite the propellant canister of outer casing and utilizes the difference between the detonating velocity of explosive and the burning rate of propellant to realize perforating first and then gas fracturing, thus improving the flow conductivity of the formation in the area near well and attaining production stimulation. This technology has been applied in more than 120 wells in China with 100% success rate and obvious production response.

4. Perforation Technologies for Higher Operating Efficiency

The String Technology for One-time Perforation Completion and Full-bore Perforation Technology are developed for enhancing the operating efficiency. The technologies can decrease the number of times for tripping, increase the efficiency of completion operation, save time and cost of well testing, decline the pollution to productive reservoirs and enhance the deliverability. So these perforation technologies are safe and efficient. They have been employed widely in large oil and gas fields in China, creating favorable economic efficiency and social benefits

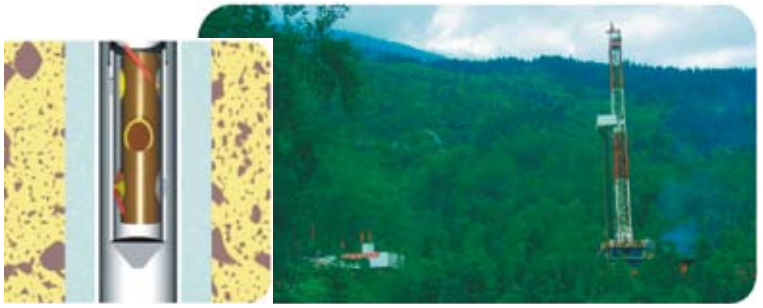
4.1 String Technology for One-time Perforation Completion

The String Technology for One-time Perforation Completion uses the oil tube to transport the perforating gun to the target formation, and then after the ignition of perforation, adopts the technology of throwing perforating gun to make the gun fall into the rat hole, thereby making the whole completion string keep unblocked. Meanwhile, the technology can finish the successive activities (e.g. fracturing, production log) without the need to trip out the pipe string, which is fit for the highly productive oil and gas wells that were put into production in one time and have rat holes long enough to throw the perforating gun.

4.2 Full-bore Perforation Technology

The technology uses the oil tube to transport the perforating gun to the target formation, and then after the ignition of perforation, adopts the technology of throwing perforating gun to make the gun fall into the rat hole, thereby making the whole completion string keep unblocked. Meanwhile, the technology can finish the successive activities (e.g. fracturing, acidation, production log) without the need to trip out the pipe string.

It is fit for the straight well and inclined well with the casing diameter ≥5″ and can be used for the straight well and inclined well under the condition of balanced drilling. CNPC owns 2 proprietary technologies: “Double-barrel-style perforating gun for oil and gas wells” and “A kind of full-bore perforating gun assembly for oil and gas wells”.



3 Typical Cases

1. Perforation for Ultradeep Well in Well Jianmen 1

Well Jianmen 1 is located in Longgang block of Sichuan, with the total well depth of 22867.18ft, bottomhole pressure 17391.3psi and bottomhole temperature 347°F. In July 2008, CNPC successfully finished the perforation operation in the well with the Perforation Technology for Ultradeep Well.

2. Perforation for Horizontal Well in Gas Field with High Sulfur Content

Well Luojia 11 is located in Luojiazhai structural block of Kai County of Chongqing City, with the total well depth 13592.35ft, perforation interval 1421.6ft, effective perforation thickness 1219.8ft and H2S content as high as 130.425g/m3. By use of Type-89 perforation gun for the horizontal well, the perforation phases have 9 kinds of assemblages such as horizontal, horizontal and upward 30°, horizontal and downward 30°. By use of the partition detonation for ensuring safe work practices and reliability, 5,442 perforation charges were fired completely with 100% emissivity.

3. Oriented Perforation in Well Sui 54

Based on the well logging data of Well Sui 54 and the analysis and research of the regional geostatic stress, it is determined that the maximum geostatic stress direction of the perforation horizon in the well is NE100° and the formation fracture pressure gradient

is about 3.5. As per design, the oriented perforation was conducted, with the perforation density of 16 hole/m. During the operation, the surface instrument was used to monitor the direction of the perforating gun, sand fracturing was adopted during perforation and fracturing was decreased at the well mouth, hence the stimulation of oil and gas.

4. Compound Perforation Operation in Well LG27

The total well depth of Well LG27 is 17257ft. In 2008, Feixianguan Formation of the well was operated by adopting the joint operation of compound perforation, acidification and testing, thus achieving excellent results and realizing the obvious stimulation of oil and gas.

4 R & D Equipment

HTHP (High Temperature & High Pressure) Laboratory

The HTHP test equipment is composed of ultrahigh pressure vessel, three main systems (ultrahigh pressure system, self-compensating pressure system and heating cycle system for conduction oil), two secondary systems (cooling water system, compressed air system) and the observation & control system. For the system, the maximum operation temperature is 410°Fand maximum pressure 28985. 5psi.

The equipment is the experimental means for the development of the high-performance casing perforating tools and the research of the law of product performance change, i.e. perforation charge, perforating gun and letting-in tools under high temperature and high pressure.

Three-Coordinate Detection System for Die Inspection

Multifunctional Physical and Chemical Analyzer for Powder

5 Qualification and Standard

CNPC has qualifications of international and internal certification as below:

6 Expert Team

Chen Feng (Expert in perforation completion) He has presided over and finished many basic researches in “Research of Perforation Technology for Well under Pressure in Wellhead”, “Research of Perforation Technology for Horizontal Well”, “Integration and Application Research of New Technique of Compound Perforation”, etc. He has conducted new industrial researches and compiled the executive plans for special perforation subjects in important national logging projects. He has obtained “Sun Yueqi Excellent Youth Science and Technology Award” and many provincial and ministerial-level awards.

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Liu Fangyu (Expert in perforation completion) He has joined in the tackling of key difficult scientific and technological subjects on perforation since the “Eighth Five-Year Plan”, and obtained one state-level major achievement award. He has presided over and taken part in the research and development of international-level projects—“Oriented Perforation”, “Compound Perforation”, “Dynamically Underbalanced Perforation”, “Optimization of Perforation Scheme”. He has obtained many provincial and ministerial-level awards. He has published more than 10 research papers in core journals and obtained one patent for invention. E-mail: liufangyu@petrochina.com.cn Phone: 013836787666

Pan Yongxin (Expert in theoretical research of detonation, perforator design and manufacturing engineering) For many times, he has presided over or taken part in and finished many projects including “Development for Model-127 Perforator”, “Development of Stimulation Technology for Well Perforation” and “Complete Technological Research of High Temperature & High Pressure Resistant Perforators of Model 89 and 102”. He has obtained many provincial and ministerial-level awards. He has published more than 10 research papers in core journals and obtained one patent for invention.

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Luo Hongwei (Technical expert in development of perforation charge) He has presided over and finished many basic research and product development projects including “Development of Perforating Charge for Ultradeep Penetration”, “Development of High Temperature Perforating Charge”, “Research of Calculation Procedure and Computation Software of Perforation Charge for Oil and Gas Wells” and “Development of Perforation Charge with High Density and Large Aperture”. He has obtained many provincial and ministerial-level awards and 5 patents.

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Tang Kai (Technical expert in operation and engineering of perforation) He has presided over or taken part in the research of more than 40 projects including “Research of Extreme Overbalanced Perforation Technology”. He has obtained many provincial and ministerial-level awards and obtained 5 patents. He has presided over or taken part in the perforation project designs and on-site technical support of Block Kela 2 in Tarim Oilfield and Block Longgang in Sichuan, etc. He has obtained 14 patents.

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Du Mingzhang (Technical expert in development of perforation charge, academic pacemaker in the research on perforation charge technology of deep penetration) He has presided over or taken part in more than 20 projects and key technical problems successively, including “Perforation Charge Technology of Deep Penetration”, “Perforation Charge Technology of Large Aperture”, etc. He has obtained 2 patents and many provincial and ministerial-level awards.

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Liu Yongjun (Technical expert in operation and engineering of perforation) He has successively presided over or taken part in more than 30 projects, including “Full-bore Perforation Technology”. He has obtained many provincial and ministerial-level awards. He has published the paper “Assorted Perforation Technology for Underbalanced Drilling” and many other research papers, and obtained 2 patents.

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Fu Daixuan (Technical expert in development of perforation charge technology) He has presided over and participated in more than 30 projects and technological subjects, and developed the perforators for ultradeep penetration, through-tubing without gun body, large aperture, etc. He has published over 10 research papers and obtained 5 patents.

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