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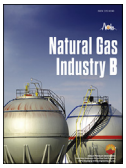

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Research Article

Technologies in deep and ultra-deep well drilling: Present status, challenges and future trend in the 13th Five-Year Plan period (2016–2020)☆

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Abstract

During the 12th Five-Year Plan period (2011–2015), CNPC independently developed a series of new drilling equipment, tools and chemical materials for deep and ultra-deep wells, including six packages of key drilling equipment: rigs for wells up to 8000 m deep, quadruple-joint-stand rigs, automatic pipe handling devices for rigs for wells being 5000/7000 m deep, managed pressure drilling systems & equipment, gas/fuel alternative combustion engine units, and air/gas/underbalanced drilling systems; seven sets of key drilling tools: automatic vertical well drilling tools, downhole turbine tools, high-performance PDC bits, hybrid bits, bit jet pulsation devices, no-drilling-surprise monitoring system, & casing running devices for top drive; and five kinds of drilling fluids and cementing slurries: high temperature and high density water-based drilling fluids, oil-based drilling fluids, high temperature and large temperature difference cementing slurry, and ductile cement slurry system. These new development technologies have played an important role in supporting China's oil and gas exploration and development business. During the following 13th Five-Year Plan period (2016–2020), there are still many challenges to the drilling of deep and ultra-deep wells, such as high temperatures, high pressures, narrow pressure window, wellbore integrity and so on, as well as the enormous pressure on cost reduction and efficiency improvement. Therefore, the future development trend will be focused on the development of efficient and mobile rigs, high-performance drill bits and auxiliary tools, techniques for wellbore integrity and downhole broadband telemetry, etc. In conclusion, this study will help improve the ability and level of drilling ultra-deep wells and provide support for oil and gas exploration and development services in China.

Keywords: Deep well; Ultra-deep well; Drilling techniques; Progress; Challenge; Strategy; CNPC

Since the 12th Five-Year Plan, China National Petroleum Corporation ("CNPC") has worked systematically on the challenges to drilling and completion of deep and ultra-deep wells, with the support of research projects from the state, CNPC and PetroChina. As a result, CNPC has independently developed a series of new equipment, tools, instruments, and chemical materials to support the operations in the Kuqa piedmont of the Tarim Basin and the Sichuan–Chongqing gas region in the Sichuan Basin. Meanwhile, the capacity of drilling deep wells has gradually improved with the continuous advancement of drilling equipment and technologies.

At present, global oil and gas exploration and development is facing severe challenges induced by poor quality of resources, complicated oil and gas targets, and strict requirements of safety and environmental protection. Working targets are turning from shallow layers to deep and ultra-deep

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layers. Under this background, deep and ultra-deep well drilling technologies encounter new problems and challenges.

1. Technological progress in deep and ultra-deep well drilling during the 12th Five-Year Plan period

During the 12th Five-Year Plan period, with the support of national oil and gas special projects, CNPC special projects and other projects CNPC independently developed a series of core technologies and equipment, such as automatic vertical well drilling system, managed pressure drilling, and innovative drilling rig, which helped to improve CNPC's self-sufficiency and core competitiveness. The improving optimized and fast drilling/completion technologies for deep and ultra-deep wells drove the time efficiency of complex accidents to drop continuously and the drilling cycle to shorten significantly, thus effectively contributing to the increase of oil and gas reserves and quick production in some key areas like the Kuqa piedmont of the Tarim Basin and the Anyue gas field of Sichuan–Chongqing gas region [1–11]. Meanwhile, the quantity of deep and ultra-deep wells grew rapidly in recent years, as shown in Fig. 1.

The average drilling cycle of available wells in key areas of the Kuqa piedmont was 290 days in 2015, shorten by 44% and 237 days fewer than that in 2010, and the drilling cost per well was more than CNY10 million. In the Dabei–Keshen block, the time efficiency of complex accidents was 6.2% in 2010, 55.3% lower than that in 2010. From 2014 to 2015, 23 ultra-deep wells over 7000 m were drilled completely, recording an average drilling cycle of 315 days, 347 days fewer than that in the Well Keshen 1 completed in 2010. Key drilling indices for the Kuqa piedmont during the 12th Five-Year Plan period are shown in Table 1. In the Anyue gas field in Sichuan–Chongqing gas region, the drilling cycle of the 5000–5800 m exploratory wells targeting the Sinian was 189 days in the first round and decreased to 149 days in the third round. In the Cambrian Longwangmiao Fm gas reservoirs, the average drilling cycle of vertical wells was only 97 days, and that of horizontal wells was 146 days or only 114 days as the shortest, contributing greatly to the efficient development of the Longwangmiao Fm gas reservoirs.

Table 1
Main drilling indice for Tarim Kuqa piedmont area in the 12th Five-Year Plan period.

Year	Drilled depth/m	Drilling cycle/d	Penetration rate/(m h^{-1})
2011	6774	478	1.49
2012	6318	330	2.26
2013	6480	270	2.45
2014	6897	320	2.38
2015	7341	330	2.71

1.1. Rigs for 8000-m deep wells and quadruple-joint-stand rigs for 9000-m deep wells were developed rapidly and successfully as the major drilling equipment in the piedmont [12–14]

With the innovative design concept, rigs for wells up to 8000 m were developed rapidly and successfully as a supplement to domestic rigs, since the 7000-m deep well rigs suffer inadequate load under large casing setting depth and the 9000-m deep well rigs are too costly, depending on the conditions in the Tarim piedmont and other areas. During the 12th Five-Year Plan period, 23 rigs for wells up to 8000 m deep were used widely as the major drilling equipment for the complex deep wells in the Tarim Kuqa piedmont. The salt layers at the large casing setting depth could be sealed in one operation, and the casing program changed from “five sections” to “four sections”. With the 8000-m deep well rigs in use, the purchase cost reduced by about 20% and the drilling operation expenditure dropped by 37% compared with the 9000-m deep well rigs.

With the innovative concept of “quadruple-joint-stand”, the first quadruple-joint-stand rig for 9000-m wells was developed in China and successfully applied in the drilling of Well Dabei 305 with 7515 m in depth in the Tarim Basin. Compared with the three-joint-stand rig used in the adjacent 9000-m well, the quadruple-joint-stand rig achieved a tripping speed of 15% higher, downhole complexities of 20% less, a drilling cycle of 6% shorter, and a drilling cost of CNY4 million less. Thus, it presented as a new efficient tool with higher ultra-deep well drilling speed and efficiency, and a supplement to supporting optimized and fast drilling and completion technologies for deep and ultra-deep wells.

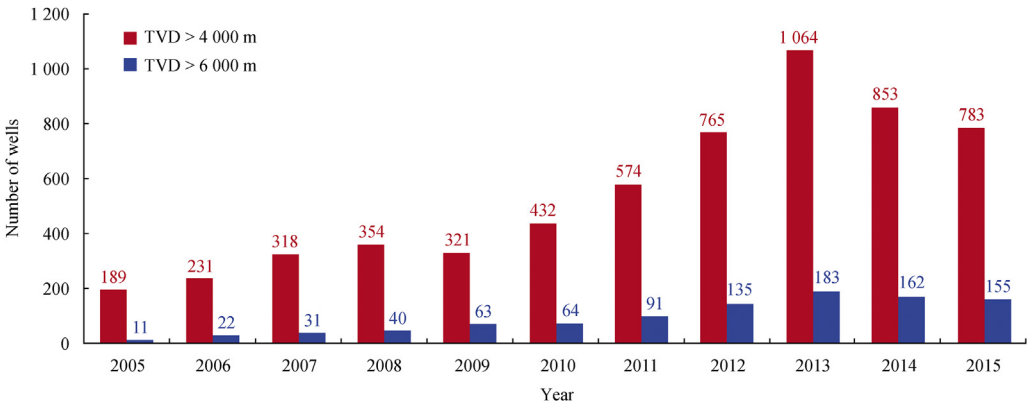

Fig. 1. Number of deep and ultra-deep wells of CNPC in recent years.

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