Breakthrough in drilling and completion equipment and key technologies for 8000m-class ultra-deep wells onshore China

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Abstract. With the exploration and development of a group of deep ultra-deep large oil and gas fields in Tarim basin and Sichuan Basin, deep oil and gas reservoirs will be the main productivity replacement area and the main exploration focus area. Drilling and completion still face severe challenges such as high temperature and high pressure, complex pressure systems, complex accidents and poor drillability. This paper describes the technology of domestic oil and gas fields with 8000m level drilling and completion. Considering the demand of exploration and development of local oil and gas fields while standardizing the international advanced level, the insufficiency of technology and equipment improvement demand of each block are discussed, and the research direction of technology and equipment is prospected.

Keywords: Class 8000m onshore drilling, Ultra-deep well drilling and completion technology; Ultra-deep well equipment.

1. Introduction

In recent years, the number of deep and ultra-deep wells drilled in China has increased rapidly, and by 2020, the number of 6000m-class deep wells exceeded 1,000, with more than 50 ultra-deep wells completed and 8000m-class landmark wells drilled and completed, such as Wutan 1, Zhongqiu 1, Keshen 21, Luntan 1, Gaotan 1, and Hutan 1, which greatly promoted the deep and ultra-deep exploration and development in key areas such as the mountain front area of the Tarim Basin, the Tai Basin area, the marine carbonates of the Sichuan Basin, and the southern edge of the Jungar Basin in China. At the same time, the key technologies and equipment for deep and ultra-deep wells have been gradually localized [1], and the successful application of localized technologies such as tower standard series well structure and poly-sulfur oil-based drilling fluid [1] has greatly improved the drilling speed. The average drilling duration of ultra-deep direct wells in 2015-2020 decreased by 49% and the mechanical drilling speed increased by 106% compared with 2011, achieving more satisfactory milestones. However, there are still some major challenges to be overcome, such as the dense and difficult to drill ultra-deep rock, the drilling and completion technology under high temperature and pressure is basically a blank, and the low degree of deep reservoir transformation. Therefore, based on the front-end technologies successfully applied in various aspects of domestic 8000m-class drilling, this paper benchmarks the current level of the industry and proposes the future development direction of various technologies.

2. New Challenges for Drilling and Completion Engineering in China's Ultra-deep Well Exploration and Development and Response

The difficulties of ultra-deep wells mainly lie in the multi-pressure system, the damage to drilling equipment caused by ultra-high temperature and ultra-high pressure, and the inefficiency of rock breaking in deep formations due to working conditions such as high rock hardness, slow drilling speed, and the non-conformity between the multi-pressure system and the structural level of the well body [2]. Drilling equipment to adapt to the temperature also needs to be improved, can adapt to the pressure of 130MPa or more, the temperature of 200 ℃ less types of drilling equipment, need further research and development, there is no adaptation to the pressure of 200MPa, the temperature of 260 ℃ drilling equipment. The Yuanba area has developed new rock-breaking tools such as TorkBuster torsional impactor and pregnant diamond drill bits to meet the local characteristics. The average drilling speed with TorkBuster torsional impactor increased by 134.62% compared with the same conditions in the neighboring section. The mechanical drilling speed was increased nearly twofold with the use of the Pregnant Diamond Bit+Turbo Drill Tool compared with the same borehole conditions in the neighboring wells [3].

Drilling encounters such as salt paste layer, plastic mudstone and other special strata also have the problem of easy plastic flow or expansion, shrinkage, and many must sealing points [4]. In addition, ultra-deep well completions have a series of problems such as high wellhead pressure affecting the quality and speed of cementing and the inability to accurately evaluate the capacity of sulfur-bearing formations and to accurately predict sulfur deposition and propose corresponding unblocking techniques [5].

3. New breakthroughs in engineering technology

3.1. Well structure design and unconventional API casing

The actual well structure used in the Rotation 1 well was partially different from its initial design in order to cope with the problems such as many necessary sealing points. The well was a risky exploration well, so there was insufficient knowledge of the stratigraphy downhole, and there was an error in the actual depth of the stratigraphy downhole.

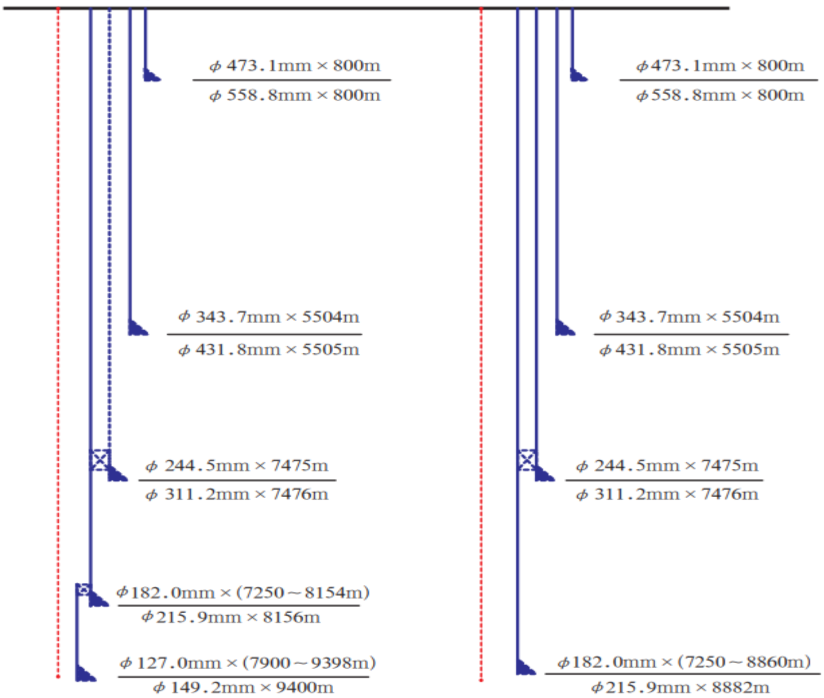

Figure 1. Comparison of designed well (left) and actual well (right) structure.

Considering the fact that specific information is not available for deep formations and inconsistent pressure systems, the accident rate is higher when the four-opening well structure is drilled into salt formations or other complex situations, and the five-opening well structure is selected comprehensively [6].

3.2. High temperature resistant liquid system

The drilling fluids used in the field were benchmarked and analyzed in indoor experiments against their field use. The results of their stability under high temperature conditions are listed in Table 1, from which it can be seen that they have better stability against high temperature compared to poly-sulfur drilling fluids under the same conditions.

Table 1. High temperature stability of high performance water-based drilling fluids.

Well name	Remark	depth /m	ρ/g/cm3	FV/s	PV/mPa·s	YP/Pa	Gel/Pa/Pa	FL_{HTHP}/mL
Y1		3913	2.01	38	20	7.5	2.5/5.0	7.8
		3993	2.13	40	22	7.5	2.5/5.5	7.6
		4039	2.13	43	23	8.0	2.5/6.0	7.2
		4079	2.36	48	30	8.0	3.0/6.5	7.2
			2.36	46	25	8.0	3.0/6.0	7.0
	200℃120h		2.36	56	53	11.0	8.0/13.0	8.6
	100h return		2.36	57	54	11.0	7.5/14.0	8.8

After analysis and comparison, the drilling fluid had good rheological properties, low filtration loss, and low annular friction equivalent at densities ranging from 2.24 to 2.36 g/cm3 and temperatures ranging from 192 to 200 °C [7].

The first area of Shunbei oil and gas field belongs to carbonate rock fractality-cave type, so it is difficult to achieve plugging effect by using low density plugging agent. In order to achieve better leak prevention and plugging effect, the plugging agent adapted to this formation was studied. Polypropylene fibers of different lengths were compounded and then added into the same isolation solution with different addition amounts respectively. The best pressure-bearing capacity based on the experimental results reached 1.5 MPa, which achieved the purpose of preplugging [8].

When the depth of exploration and development is gradually deepened, the performance of cement paste in ultra-high temperature condition has new requirements. The main technical difficulty of ultra-high temperature cement paste is that the thickening time of cement paste should meet the construction requirement time, low water loss and good settling stability. Therefore, the key to the design of cement paste is to maintain the basic performance of water loss reducers, retarders and stabilizers under ultra-high temperature. The thickening time and water loss can be controlled, the settling stability is good, and the compressive strength of cement remains unchanged under ultra-high temperature. Cement slurry formulation A and cement slurry formulation B with 4% stabilizer DRK-3L were analyzed for comparative settling stability at different temperatures.

Table 2. Settlement stability of different cement paste formulations at 160-210°C.

Formulation	T/℃	Density difference between top and bottom /(g·cm3)
A	160	0.02
A	170	0.02
A	180	0.03
B	190	0.03
B	200	0.03
B	210	0.04

From Table 2, it can be seen that the cement paste has good high temperature stability in the temperature range of circulating temperature 160-210℃, and the high temperature suspension stabilizer DRY-S2 can keep the density of cement paste unchanged to a certain extent at high temperature 160-180℃. If the temperature reaches 190~210℃ can use DRY-S2 and DRK-3L to control the density of cement paste with each other.

The comparison of the compressive strength of cementite at different temperatures for cement paste formulations C and D showed that formulation C lacked 10% of DRB-3S compared to formulation D, but had 30% more quartz sand. The high temperature mechanical evaluations at 230°C and 250°C for both cases respectively are shown in Table 3.

Table 3. Compressive strength of cement stone at different curing temperatures.

Formulation	T/℃	P_{7d}/MPa	P_{28d}/MPa
C	230	38.8	19.9
C	250	31.4	13.2
D	230	47.8	50.4
D	250	55.4	56.1

As can be seen from Table 3, the 7d compressive capacity of formulation C using quartz sand with DRB-2S reached 30MPa, but the 28d compressive strength was much lower. It can be found that there is a significant difference in the rate of decline at different temperature cases, with the 28d compressive capacity declining by 48.7% when the temperature reaches 230°C, and the 28d compressive strength decreasing by 58.0% when it reaches 250°C. When the temperature was around 230°C to 250°C, the 7d compressive capacity reached more than 45 MPa, but the 28d compressive capacity remained unchanged [9].

4. New breakthroughs in drilling supporting equipment and tools

The load problem caused by the drilling depth of ultra-deep wells should not be ignored, for example, the Chuanke 1 well in Southwest Oil and Gas Field, whose design lifting load is over 7000kN, can reach a theoretical drilling range of 12,000m by applying the ZJ120 electric drilling rig to drill into the marine formation, meeting the design requirements while basically realizing the localization of equipment. In addition, the FB-2200HL drilling pump, on the basis of maintaining the maximum pressure of 52MPa of F-1600HL, has increased the rated displacement from 51.85L/s to 77.65L/s, which can better serve the 8000m and drilling rig related needs.

We have made breakthroughs and new advances in many technologies such as 8000m automated drilling rig, fine pressure control drilling equipment, deep continuous tubing workover, high-efficiency PDC bits and drilling speed-up series tools, and high-performance expansion tubing.

The titanium alloy drill pipe independently developed by Bohai Nengke Drill Pipe Company adopts the third generation of double-shoulder high torsional resistance BHDX thread technology, which has the features of smaller outer diameter of the joint, more wear resistance, larger inner diameter of the joint, higher hydraulic efficiency, asymmetric tooth design and better torsional resistance of the double-shoulder thread structure. Compared with ordinary API threaded all-titanium alloy drill pipe, this drill pipe can increase the torsional strength by 70%, which can meet various drilling requirements such as large water hole, high torque and harsh composite load, and is especially suitable for drilling ultra-deep wells and ultra-long horizontal wells with complex ground conditions.

The drill bits used in the East China Sea area are prone to wear during drilling, especially in the formations below the Huagang Formation in the East China Sea area. In order to improve the wear resistance of the drill bit, we designed the drill bit with tapered rear teeth, spiral design, deepened chip discharge groove, TSP polycrystalline block embedded in the top, diameter-preserving teeth and inverted eyelet teeth, which not only facilitate the diameter preservation but also enhance the diameter preservation ability. The drill bit material was changed to a higher strength material to increase the impact resistance and abrasion resistance by 25% and 30%, respectively [10].

5. Conclusions

For a considerable period of time in the future, China needs to continue to break through the key core technologies for fast drilling of ultra-deep wells, and achieve independent control of high-end equipment tools. Follow the theme of the times, that is, green low-carbon drilling, clean production. At the same time, digital intelligence is needed to support quality and efficiency improvement and high-quality development.

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