

Deep Well and Ultra-Deep Well Drilling and Completion Technology Optimization and Application of Kuche Piedmont Area

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Abstract. In recent years, the exploration and development of China's Tarim Basin has moved towards ultra-deep and complex areas. With the increase in well depth and the influence of the geological characteristics of the Kuche Piedmont area, a series of drilling problems for 8000m-level ultra-deep wells in this area have been caused. As a result, a series of new drilling and completion technologies have been formed: ①Based on the tower standard I type well structure, the improved tower standard II-B\II-C type well structure is used to solve the drilling of two sets of salt formations. Difficulties; ②Optimizing UDM-2 oil-based drilling fluid, achieving an average hole diameter expansion rate of only 6.82%, reducing lost circulation and other complications; ③Designing and optimizing a new type of multi-edge PDC bit to significantly increase the average ROP; ④Application The industry-leading pre-measurement resistivity technology successfully predicts the salt bottom; ⑤The application of fine controlled pressure cementing technology to achieve effective sealing of high-pressure saline formations. In recent years, the Kuche Piedmont Block in the Tarim Basin has continued to tackle key problems in the application of ultra-deep well drilling and completion technologies, and has successfully reached a new level of 8000m, which has played an important role in supporting the development of deep oil and gas exploration and development business.

Keywords: Deep and ultra-deep well, drilling equipment, drilling and completion technology, geological difficulties.

1. Exploration and development status of Kuche piedmont area

The Kuche Mountain Foreland Basin is located between the South Tianshan Orogenic Belt and the Tabei Uplift. The oil and gas fields in the Kucheqian area have both fractured tight reservoirs and ultra-deep and ultra-high pressure characteristics, which are specifically due to the large burial depth (6500~8000m). It has strong compaction effect, high in-situ stress, and also has the geological characteristics of poor reservoir matrix physical properties and well-developed fractures. With the development of exploration and development in the ultra-deep and complex areas in the Kuche Piedmont area, a series of drilling problems for 8000m-level ultra-deep wells in this area have been caused:

(1) The Kuche Foreland Basin has the characteristics of deep burial depth (over 8000m), high formation pressure (greater than 130MPa), high temperature (greater than 185°C), high in-situ stress (minimum horizontal principal stress greater than 130MPa), complex formations encountered, etc., It puts forward extremely strict requirements on the modification of pipe string, downhole tools and modification fluid.

(2) The gravel layer in the Kuche piedmont area contains gravels of different compositions in multiple sets of formations in the longitudinal direction. During the drilling process of conventional PDC bits, it is very easy to cause early damage to the cutting teeth due to the positive impact of the gravel, which in turn causes the ROP to change. Slow, low bit footage and high bit consumption have severely restricted the efficient exploration and development of tight sandstone reservoirs in the piedmont ^{[1][2]}.

2. Optimization of 8,000m ultra-deep well structure

In view of the structural characteristics that the composite salt-gypsum layer in the foreland area of Kuche Mountain is generally buried at a depth of more than 5000m, the length of the open hole section above the salt is more than 5000m, and the formation pressure coefficient spans large. It is necessary to run a technical casing to isolate the low pressure layer on the salt, which is a composite salt. Safe drilling of the gypsum layer provides guarantee. For this reason, the tower standard II well structure was designed to achieve significant improvements such as completion pipe strings of 5" and above, and sidetracking large-size wells.

Table 1. KS-A well casing design and check

Casing procedure	Steel grade	Wall thickness (mm)	External collapse resistance			Internal pressure resistance		
			Rated strength (MPa)	Safety factor	Stress intensity (MPa)	Rated strength (MPa)	Safety factor	Stress intensity (MPa)
Surfaces casing	J55	12.7	5.3	2.43	5.3	16	6.88	16.3
Intermediate casing	TP110V	13.88	24	1.89	24	33	1.23	35.3
	TP140V	13.84	60.6	1.18	60.55	81.3	1.25	89.56
Drilling liner hanger	TP155V	15.12	132	1.29	131.55	116	1.91	116.33
Drilling liner hanger	TP140V	12.09	152.66	1.93	152.27	145.97	292	146.3
Casing tie-back	TP140V	12.7	90	1.82	89.92	105	1.26	105.43

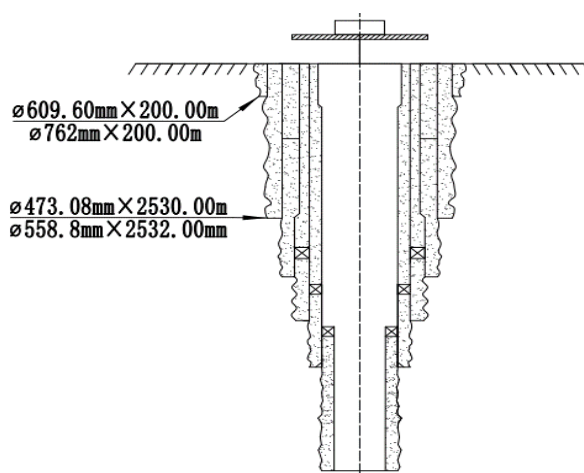


Figure 1. Tower II-B well structure (KS-B well)

In view of the development of two sets of salt formations in some blocks, the tower standard II structure Based on the research and development of 14 3/4" casing to seal the first set of salt formations and 8 1/8" casing to seal the second set of salt formations, the tower standard II-B six-open six completion body structure was designed to solve the two problems. Set of drilling problems in salt formations.

3. Ultra-deep well drilling fluid technology

After the exploration and development of the Kuche Piedmont block has reached a new level of 8000m, the biggest challenge facing the demand for drilling fluid is high temperature resistance (above 170°C). After using UDM-2 oil-based drilling fluid, not only the wellbore is very regular, the average caliper expansion rate is only 6.82%, and the initial shear force is only 2-3MPa, which greatly reduces lost circulation and other complications. And compared with the application of water-based

drilling fluid in the neighboring area, the average daily footage is increased by 67.85%, and the construction period of a single well is saved by 53.75d^[3]. Most importantly, UMD-2 oil-based drilling fluid can withstand high temperatures of 200°C, so this drilling fluid is the most reliable and experienced choice.

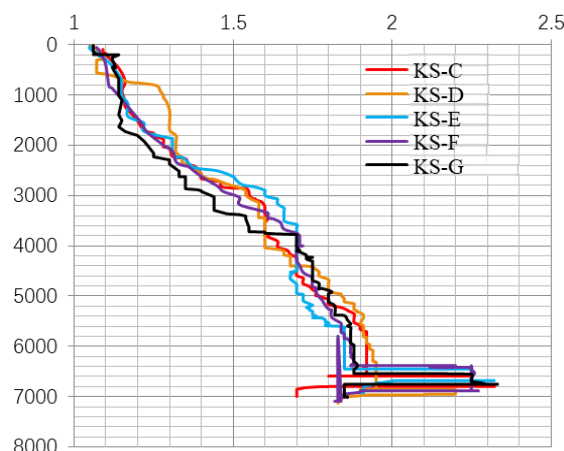


Figure 2. The drilling fluid density of KS-C and adjoining wells

4. Increase of ultra-deep well drilling speed

The gypsum-salt rock layer in the Kuche Piedmont block is complex, with deep burial depth and large changes at the bottom of the salt layer. The sub-salt stratum has ultra-deep burial, high temperature and ultra-high pressure, high degree of compaction, high in-situ stress, and abrasiveness. Strong, poor drillability, well-developed fractures, easy to cause sticking and lost circulation, and serious borehole wall instability^[4].

In response to the above problems, in actual application, a Bozi well adopted a new type of multi-edge PDC bit + high-torque screw combination technology of equal wall thickness, and matched vertical drilling tools^{[5][6]}, completing the well section of 3854-4739m, achieving 13 The 1/8" single-trip footage is 885m, and the ROP is 4.5m/h, creating a new record for the footage and ROP of a single bit under the conditions of three-open large-size well drilling^{[7][8]}.

In addition, special strata, such as the Kumgliemu Group strata, are encountered in drilling due to the presence of composite salt intervals. Torque impactor is a better choice. While ensuring the wellbore quality and wellbore smoothness, it converts the fluid energy of the drilling fluid into high-frequency reciprocating and uniform and stable mechanical impact energy and directly transmits it to the PDC bit^{[9][10]}. In practical applications, well KS-F uses PDC bit + torsion impactor to be applied to the gypsum mudstone section of the Kumglemu Group. Compared with conventional drilling, the torsion impactor increases the average ROP by more than 2 times.

Table 2. Application of PDC bit + torque impactor combined drilling technology^[11]

Well No.	Well section/m	Layer	Bit size/mm	Bit type	Footage/ m	Average rate of penetration/ m·h ⁻¹	Note
KS-F	4437~4545	Kumugeliemu group	241.3	VYZ613 DGLU	108	0.82	Warui bit
	4545~4553			MS1952SS	8	0.44	Beste bit
	4553 ~4567			U519s	14	0.82	Torque
	4567~4974			U513s	397	2.56	impactor

5. While drilling measurement technology of ultra-deep well

Most wells in the Kuche Piedmont block need to be drilled through the salt layer. For these wells, it is very important to drill through the salt layer safely and then accurately install the casing at the

bottom of the salt layer. The complicated formation conditions cause the MWD tool to fail due to various reasons ^{[12][13]}. The downhole failure statistics of MWD tools are as follows:

Table 3. Actual effect statistics of 7,000-8,000m while drilling tool in Kuche piedmont area

Well depth/m	Instrument model	Failure type	Lost time/h
7370	COMPASS-MAD	The instrument is damaged and cannot work normally due to oil leakage of pulser chamber	26
7380	COMPASS-MAD	The walnut shells, almond shells and other particulate matters in the mud cause the instrument stuck and damaged	78
7975	APS-MWD	Suspected failure of sensor assembly	94.5
7993	APS-MWD	Suspected failure of sensor assembly	142
7993	APS-MWD	Failure of probe control mainboard. The probe cannot send instructions to the pulser and the pulser cannot work.	1195

In response to the failure of the high temperature and high pressure measurement while drilling instrument in the KS-block, the salt-gypsum layer encountered when drilling, the Deep Electro-Magnetic (EM) Look-Ahead technology is applied, which can be achieved by measuring the resistivity of the formation in front of the drill bit and real-time mapping. Detect problem formations and optimize casing positions to reduce drilling risks ^{[14][15]}. In practical applications, this technology can successfully measure 3-10 ohm.m shale layers within a range of 10-15m in front of the drill bit.

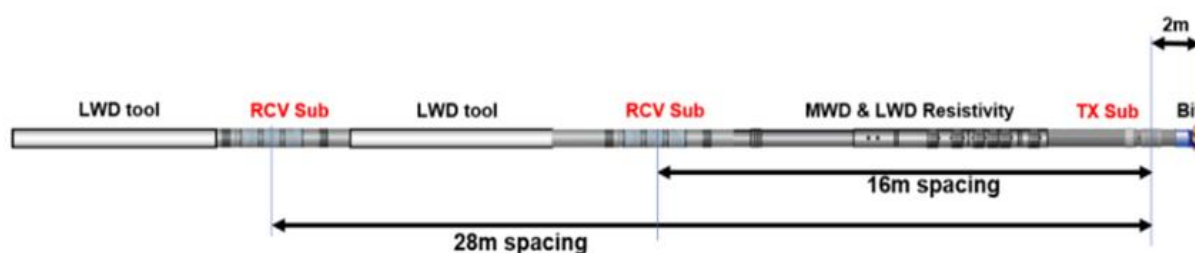


Figure 3. Typical Look-Ahead BHA with 4.75", 6.75", and 8.25" diameters that allow the look-ahead application in 6" to 17" holes.

6. Cementing technology of Kuche piedmont area

As the bottom hole temperature in the Kuche Piedmont block reaches 200°C, the bottom hole pressure exceeds 180MPa; the drilling encounters complex formations, and there is leakage in the cementing process; the basic sealing target is achieved under the condition of high pressure salt water+ salt bottom leakage in the salt-gypsum layer Difficulties: The cementing quality of the target layer is difficult to meet the long-term integrity requirements and other technical difficulties. The cementing quality of this block is generally low.

In the specific construction, the precise pressure control cementing technology was adopted to solve the problems of narrow safety density window and easy leakage of cementing ^[16]. On-site construction practice shows that the pressure control cementing technology of high pressure salt water layer can effectively reduce cementing leakage. Improve cementing quality, ensure wellbore stability and construction safety in the cementing process, and provide a new technical means for cementing operations in complex formations ^[17].

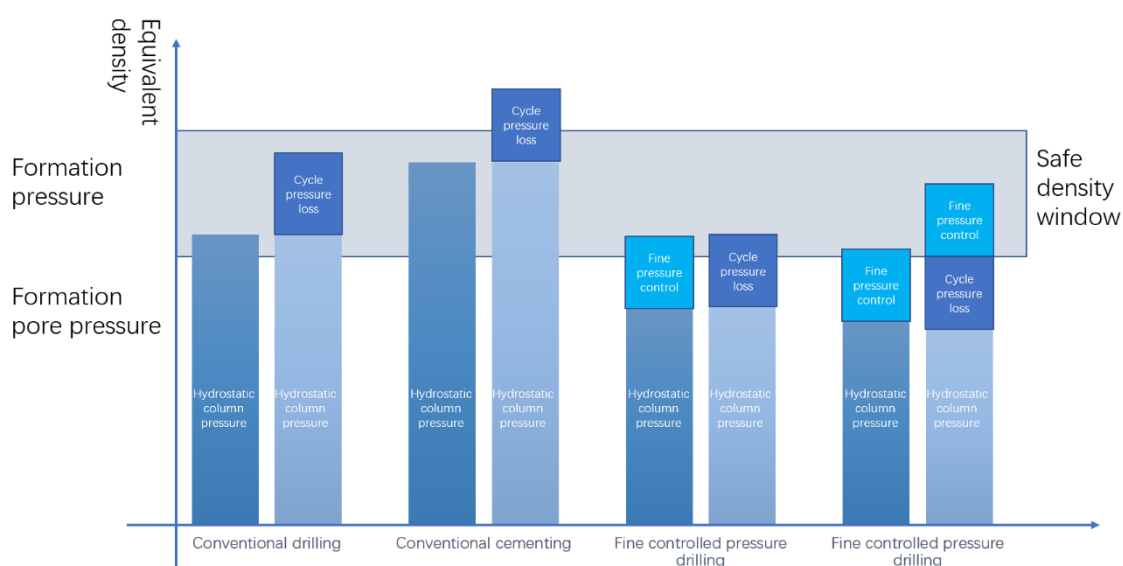


Figure 4. Control of fine controlled pressure bottom hole equal yield density

7. Conclusion and suggestions

The current exploration and development in the Tarim area has moved from 6000m-level ultra-deep wells to 7000m or even 8000m-level ultra-deep wells. The rapid development of drilling and completion technology has made breakthroughs in the design of new wellbore structures, oil-based drilling fluids, new drill bits, pre-measured resistivity identification of salt top and salt bottom, and fine control pressure cementing technology. The drilling and completion of wellbodies have continued Refreshing records in China and even in Asia has played an important role in supporting the development of China's petroleum exploration and development business and promoting the ultra-deep replacement area for oil and gas exploration and development.

As the development of oil and gas resources moves closer to the deep, the Kuche Piedmont in the Tarim Basin is still facing many technical challenges and cost pressures. It is recommended that the Kuche Piedmont in the Tarim Basin should focus on deep complex drilling during the advancement of 8000m and the completion of the well. New technologies and methods for well completion, ultra-deep well automation and high-efficiency drilling and completion new equipment and new equipment, and early drilling and completion prediction tests have been launched.

References

- [1] Li Ning, Zhou Bo, Wen Liang, et al. Research on speed-up technology of gravel layer in front of Kuche Mountain in Tarim Oilfield [J]. *Drilling and Production Technology*, 2020, 43(2): 143-146.
- [2] Zhang Haizhong, Lv Xiaoping, Li Jun, Li Qinglei, Song Hongwei. Optimization and application of personalized and efficient rock-breaking bits in Tuz block [J]. *Drilling and Production Technology*, 2021, 44(3): 10-14.
- [3] Dong Meng, Liang Hongjun, Yang Bozhong, Tao Sicai, Yu Kexin, Hu Linzhen. Drilling speed-up supporting technology for ultra-deep well in KS9 structure [J]. *Drilling & Production Technology*, 2016, 39(6): 11-13.
- [4] Jiang Tongwen, Teng Xueqing, Yang Xiangtong. Fast and efficient production production supporting technology for Keshen 8 ultra-deep ultra-high pressure fractured tight sandstone gas reservoir in Tarim Basin [J]. *Natural Gas Industry*, 2016, 36(10): 1-9.
- [5] Zhang Duanrui, Wen Tao, Pu Lei, Chi Jun, Zhou Xiaojun, Liang Hongjun, Zhao Caiting. Pilot test of "vertical drilling tool + equal wall thickness screw" speed-increasing drilling tool assembly—Taking the high-steep structure Keshen A well in front of the Kuche Mountain as an example Example [J]. *Petroleum Drilling and Production Technology*, 2020, 42(6): 684-690.

- [6] Wang Pan, Liu Xiaogang, Liu Jie, Zhao Lizhen, Song Rui, Xu Kun. Application of vertical steering tools and high-performance motors in the Bohai Sea's mid-deep drilling to increase speed and efficiency [J]. Petroleum Drilling and Production Technology, 2018, 40 (A1): 118-120.
- [7] Tian, J. L. a, b; Wei, Lai a; Dai, Liming c; Emtiaz, Shadequr Rahaman a; Islam, Ariful a; Uddin, Rasel a; Zhang, Tangjia a. Study on the mechanism of drilling speed increase considering the axial vibration of drill string. [J] Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2021, Vol.43, No.1.
- [8] Pei Yang 1; Ning Li 2; Liang Hong Jun 2; Han Yu Tian 2. Research and practice on drilling and completion technology for highly deviated wells in an extremely deep and thick salt– gypsum layer in Keshen area. [J] IOP Conference Series: Earth and Environmental Science, 2021, Vol.861, 062060.
- [9] Wang Haitao, Zhang Wei, Wang Guobin, Gan Renzhong, Li Jun, Zhang Xuefei. Drilling speed-up technology in Huanmahu Sag, Junggar Basin [J]. Petroleum Drilling and Production Technology, 2014, 36(4): 30-33.
- [10] Liu Xiaogang, Deng Jianming. Application of technology to increase the ROP in the Bohai Sea [J]. Petroleum Drilling and Production Technology, 2018, 40(6): 706-710.
- [11] Lu Xiaoping, Li Guoxing, Wang Zhenyu, et al. Test application of torsion impactor in the Silurian formation of Well Yashen 1 [J]. Petroleum Drilling Technology, 2012(02): 106-108.
- [12] Wang Haige, Huang Hongchun, Bi Wenxin, Ji Guodong, Zhou Bo, Zhuo Lubin. Deep and ultra-deep well oil and gas drilling technology progress and prospects [J]. Natural Gas Industry, 2021, 41(8): 163-177.
- [13] Silversides, Katherine L.; Melkumyan, Arman. Boundary Identification and Surface Updates Using MWD. [J] Math. Geosci. 2021, Vol.53, No.5, 1047-1071.
- [14] Liu, K. Model and control method of a downhole electromagnetic transmitter for EM-MWD system (Article). [J] Journal of Petroleum Science and Engineering. 2020, Vol.192, 107210.
- [15] Li, KS (Li, Kesai) 1; Gao, J (Gao, Jie) 1; Ju, XD (Ju, Xiaodong) 1; Zhu, J (Zhu, Jun) 2; Xiong, YC (Xiong, Yanchun) 2; Liu, S (Liu, Shuai) 1. Study on Ultra-deep Azimuthal Electromagnetic Resistivity LWD Tool by Influence Quantification on Azimuthal Depth of Investigation and Real Signal (Article). [J] Pure and Applied Geophysics. 2018, Vol.175, No.12, 4465-4482.
- [16] Chris Carpenter. Managed-Pressure Cementing Implemented in an Exploratory Ultradeepwater Well. [J] Journal of Petroleum Technology. 2021, Vol.73, No.5, 66-67.
- [17] Liu Wei, Li Mu, He Silong, Lei Wanneng, Fang Chao, Tang Lei. Practice and understanding of pressure controlled cementing in ultra-high pressure saline formation in front of Kuche Mountain [J]. Drilling and Production Technology, 2020, 43(5): 31-33.