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Study and Application of New Technology to Increase Drilling Speed of Ultra-Deep Well in Yuanba Area

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Abstract

The geologic condition in Yuanba Area is quite complex. The drilling problems of formation leakage, pressure differential sticking, narrow density windows and other issues are more and more prominent. Drilling efficiency is low with long drilling cycle because of abnormal complex engineering geological characteristics such as thick continental formation, interbeded sand shale, poor drillability, ultra-high pressure in J_1z and T_3x formation, narrow pressure window. 12 completed wells in Yuanba area are analyzed, the conclusion can be draw that improving drilling efficiency in Yuanba region is quite potential if complexity underlying can be decreased and ROP can be improved. In view of this, the matching drilling technologies and tools are introduced and applied, the result show that optimization technology of casing program, bit optimization, gas drilling technology, compound drilling technology and corresponding new tools has made great success in Yuanba area, the average ROP was increased by 20.25%, drilling period was shortened by 18.33%, and the average complex accident handling time was reduced by 25.40%, which provides a good reference for ultra-deep well drilling.

Key words: Ultra-deep well; Gas drilling; Bit optimization; Compound drilling; Drilling ROP

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INTRODUCTION

Yuanba area is full of large scale reef flat reservoir, locates in the south to Jiulong structural belt and west to Tongnanba anticline belt. It is another key exploration area of Sinopec after Pu Guang gas field, and it has been developed the dominant replacing position of transferring Sichuan gas to east project. However, the reservoir formations are buried deeply and have high hardness; all these disadvantages bring lots of difficulties for the highly-efficient drilling including flooding, well kick, well collapse, high hydrogen sulfide bearing and so on (Liu & Zhu, 2005; Yu, 2010). In order to speed up the progress of exploration and development, the main influence factors of ROP are studied in Yuanba area and the matching drilling technologies and tools are introduced including casing program optimization, gas drilling technology, Managed Pressure Drilling technology, bit optimization, compound drilling technology, rock-breaking tools, down hole tools and ultra-deep well cementing in this paper.

1. SURVEY OF ULTRA-DEEP WELL DRILLING IN YUANBA AREA

From May 2006 to May 2010, 30 wells have been drilled with 16 completed wells (13 vertical wells and 3 sidetracking well) and 14 operating wells (13 vertical wells and 1 sidetracking well).

Statistical data of 12 vertical wells are summarized (shown in Table 1) to draw the conclusion that the average drilled depth is 7044m, drilling circle is 469.06d, and completion circle is 528.74d. The drilling circles of different wells vary greatly, for example, the drilling circle of well Yuanba 1 is only 164.88d while that of well Yuanba 3 is 579.88d. Among the 12 vertical wells, the average middle completion interval is 164.88d, which is 31.2% of the average completion circle; net drilling prescription is only 36.71%. If complexity and accidents can be decreased, and then the non-productive prescription will be shortened, net drilling time and production efficiency will be improved, the drilling speed acceleration of ultra-deep wells in Yuanba area still has a great potential.

Table 1
The Main Drilling Indexes of 12 Completed Wells in Yuanba Area

Circle	Well number	Drilling circle (d)	Completion circle(d)	Drilled depth (m)	Production efficiency (%)	Net drilling prescription (%)	Non-production efficiency (%)	Middle completion interval (d)
Circle 1	Yuanba 1	301.25	331.27	7170.71	97.4	48.13	2.6	94.42
Circle 2	Yuanba 2	435.5	453.33	6828	98.58	46.69	1.42	117.96
	Yuanba 3	579.88	739.88	7450	67.51	30.84	32.49	252.99
	Yuanba 4	551.25	620.77	7262	83.97	31.39	16.03	231.69
	Yuanba 5	554.55	638.83	7195	87.02	35.26	12.98	165.34
	Yuanba 101	524.92	573.34	7254.5	80.72	35.79	19.28	140.66
	Yuanba 102	450	474.13	6963	93.74	40.29	6.26	151.59
Circle 3	Yuanba 12	306.7	382.62	6882	91.19	32.37	8.81	132.44
	Yuanba 11	533.96	558.79	7027	79.08	29.55	20.92	198.32
	Yuanba 9	490	565.21	7123.5	88.03	36.89	11.97	175.87
	Yuanba 27	415.69	469.82	6565	95.39	35.12	4.61	149.31
	Yuanba 204	485.06	536.89	6812	96.97	38.21	3.03	181.79
Average		469.06	528.74	7044.39	88.3	36.71	11.7	164.88

2. STUDY ON INFLUENCE OF ROP OF ULTRA-DEEP WELL IN YUANBA AREA

2.1 Geological Factors

Drilling engineering is difficult in Yuanba area because of its old formation, hard rock and poor drillability, which goes against the increase of ROP and causes formation instability such as lost circulation, well bore collapse and deviation, statistical data study shows that:

(1) Water producing formation above J_2s can bear little pressure and is likely to lost circulation with drilling fluid heavier than 1.90 m/cm^3. Collapse is likely to occur in lower part of J_2s when gas drilling is adopted, so the conventional drilling fluid must be changed and gas drilling is limited to a shorter well section.

(2) The drillability of J_1z formation and T_3x formation is very poor, bit bouncing occurs frequently, ROP is low and drilling equipment is easy to failure. The reservoir in this section belongs to fractured gas reservoir with high pressure, low permeability and narrow pressure window, lost circulation and well kick coexist when kill the well.

(3) Due to the abnormal high pressure layer in T_1j formation, the drilling fluid is required to be heavier than 2.15 g/cm^3, thus the hold-down effect increases and the ROP decreases.

2.2 Accident and Trouble

From Table1 we can see that, the average non-production efficiency of ultra-deep wells in Yuanba area is 11.7% and some even more than 20%. The accident and trouble can be classified as followed:

(1) Drilling tools and bit problem: Sticking and breaking are likely to occur in gas drilling, sticking and bit problem are common in T_3x complex layer. Statistical data study shows that these problems take up 33.97% of the accident time in this area.

(2) Flooding and lost circulation: The heterogeneity of pressure distribution causes frequent flooding and lost circulation, which takes not only lots of time but also a great quantity of drilling fluid, and causes serious economic loss.

(3) Accident in transfer to fluid drilling: Accident occurs frequently after gas drilling is transferred to conventional mud drilling, so it has no choice but to ream, sticking is likely to occur if worse.

(4) Cementing accident: Cementing engineering is difficult because of the high temperature and uncertainty of pressure bearing capacity. The accidents frequently occur, such as lost circulation, low return velocity and poor cementing quality.

3. NEW TECHNOLOGIES TO INCREASE ROP OF ULTRA-DEEP WELL IN YUANBA AREA

According to the engineering geological characteristics in Yuanba area, through study and introduce of foreign drilling technology, the drilling technical level in this area has greatly improved recently.

3.1 Optimization of Casing Program

Well drilled in Yuanba area are generally deep, the depth of some wells is almost 7500m, and the formation pressure system is quite complex. The casing program adopted is: Φ508.0mm +Φ339.7mm +Φ273.1mm+Φ193.7mm+Φ146.1mm.

5 layers casing was adopted, which is suitable for ultra-deep well with complex pressure system; the main advantage lies in large scale section is decreased, the size of 4th spud is increased, intermediate casing is longer and the accident is decreased, the clearance between wellhole and the casing

is more reasonable, cementing quality is improved, so the casing program is widely used in Yuanba area.

In order to further improve the drilling safety and drilling speed, the casing program is optimized after repeated studies. using thick wall casing, the improved casing program is: Φ476.25mm+Φ339.7mm+Φ273.1mm +Φ177.8mm.

Casing depth is optimized, Φ476.25mm conductor is set to 700m and then set up the wellhead, which is used to isolate surface water layers, unconsolidated clay and sandy gravel, the depth can be decreased to 500m if facing water seepage on the surface. Φ339.7mm surface casing is set to 3500m, which is used to isolate collapsing formation of upper part of lower J_2x formations. Φ273.1mm intermediate casing is set to 5000m, which is used to isolate gas layers of Lei4 section in T_3x formation and unstable formation above it, thus create safe drilling conditions for next spud to drilling objective layer. 9-5/8 bit is adopted in the third spud and Φ177.8mm casing is used as Well completion casing, if drilled into the high pressure layer in T_1j formation, Φ193.7mm casing should be pre-settled and complete well with Φ146.1mm liner.

After isolating upper low pressure layer through casing program optimization, the 2nd spud is practiced with conventional drilling technology, which can not only avoid the coexistence circumstances of lost circulation and well kick as in Yuanba4, Yuanba21 and Yuanba22, but also increase the production effect.

3.2 Matching Technologies of Increasing ROP

The conventional drilling technology cannot meet requirement for rapid exploration and development of Yuanba area. In view of the difficulties of low speed, complex leakage, reservoir damage in Yuanba area, the corresponding technologies have been proposed to improve the ROP in this paper.

3.2.1 Gas Drilling Technology

In order to solve the difficulties of low speed, complex leakage, reservoir damage in Sichuan oil and gas fields, the gas drilling technology has been researched and tested since 2005.Four subject technologies have been formed including dry air drilling, atomization drilling, foam drilling and aeration drilling, at the same time, eight supporting technologies including geological adaptability evaluation, optimization design, underground fluid monitoring and control, air hammer drilling, medium conversion after gas drilling, gas coring, gas drilling horizontal well, dry casing cementing were proposed. The equipment and tools of gas drilling have realized localization of manufactures, the dry gas drilling technology has matured and been popularized (Hou *et al*., 2008). Since its 1st application in well Laojun 1 in 2005, gas drilling technologies have been important means to control well deviation and increase ROP in this section. Rich experience in solving malignant circulation loss and shale collapsing by hydration swelling in long open hole section is accumulated and matching equipment is further improved. In view of the characteristic of many water layers over this section, mist drilling is introduced on the base of gas drilling (including N_2). Until April 2010, accumulated footage of gas drilling in Yuanba area has reached 61044.18m and ROP has been greatly improved, average ROP reached 8.57m/h, which is 3~8 times of fluid drilling in northeastern Sichuan basin, the single well drilling cycle was decreased for 60~90 days, serious leakage, borehole deviation, and other complex issues were controlled. Gas drilling technology has been a core technique of in continental strata of Yuanba Area and northeastern Sichuan basin.

Statistical data of examples of typical wells using gas drilling is: average ROP reached 20.6m/h in section of 206-1540m in well Yuanba 3 and 30.72m/h in section of 648.85-1573.68m in Well Yuanba 22.

3.2.2 Managed Pressure Drilling Technology

Managed Pressure Drilling is define as a drilling technology that uses a pressurizable fluid system and specialized equipment to more precisely control the well bore pressure profile (Kozicz, 2006). The main advantages lie in it can optimize the drilling process by decreasing Non Productive Time(NPT) and mitigating drilling hazards associated with the pressure fluctuation that occur when conventional drilling techniques are used. Managed pressure drilling technology is potential in increasing drilling security and ROP of ultra-deep well drilling with narrow pressure window (Vieira, *et al*., 2008).

In 2008, pilot test was practiced in T_3x formation section (4192.00 m-4611.73 m) of well Yuanba 12, with the footage of 419.73 m and average ROP of 1.39 m/h. Comparing with ROP of 0.75m/h in the same section of well Yuanba 1, the average ROP increases by 84%, lately it was practiced in T_3x formation in well Yuanba 22 and well Yuanba 11. the statistical data as follows: the average ROP is 0.81 m/h with the footage of 91.67 m(3756.32 m-3847.99 m) in well Yuanba 22 and 1.34 m/h with the footage of 402.36 m (4494.01 m-4896.37 m) in Yuanba 11. Presently, Managed pressure drilling has been a feasible technology in J_1z and T_3x formation in Yuanba area.

3.2.3 Bit Optimization

Bit optimization technology is established based on stratigraphy and rock property, including processing of logging data, bit development and field application. The single logging parameter calculation models considering the factor of acoustic time or formation density and the multiple logging parameter calculation models are established in this block to determine the value of the rock drillability. The calculation errors that produce in the single logging parameter calculation models are corrected by the multiple logging parameter calculation models and the rock drillability profiles are found out (Figure 1).

Generally, effective roller bit should be chose and PDC bit should be avoid in continental strata section of sandstone and sandy conglomerate layer, while PDC bit can be chose in large scale section of mudstone. In order to increase ROP, PDC bit is recommended in marine strata section of T_2l formation to T_1f formation, effective roller bit is recommended in P_2ch formation, and impregnated bit is introduced in continental strata section in J_1z to T_3x formation. The results show that this method can meet the need of application in Yuanba area (Figure 2).

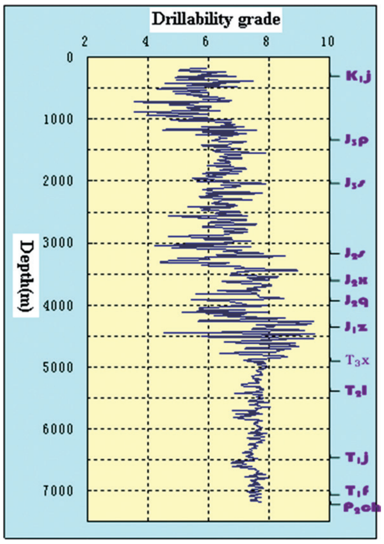


Figure 1
Drillability Grade with Depth

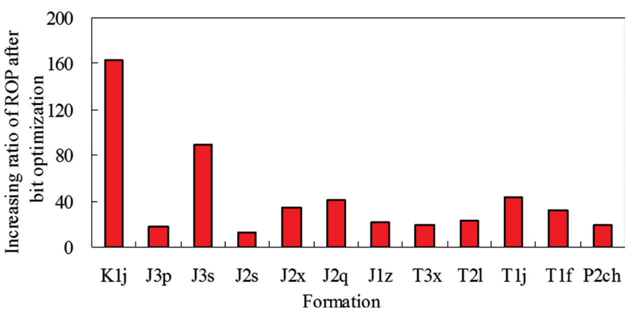


Figure 2
Increasing Proportion of ROP After Bit Optimization

3.2.4 Compound Drilling Technology

As an effective means of increasing ROP, compound drilling of PDC bit with screw is widely used in marine strata section, and pilot test in continental strata section has made much progress (Eddie & John, 1981; Feng, 2007). By optimizing of screw size, bit type, drilling parameters, ROP can be increased by effectively in marine strata. As is showed in Figure 3, ROP is increased by 15.4%, 37.32% and 73.22% in T_2l, T_1j and T_1f section using Compound drilling technology. At the same time, this technology is adaptive to fast drilling in middle and deep formation, high deviated structure, hole trajectory control in directional drilling and angle holding drilling.

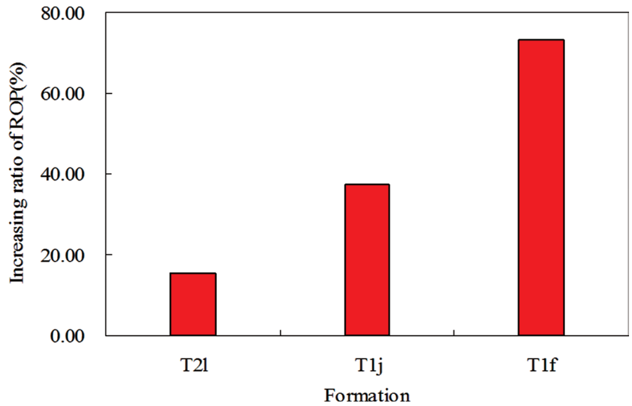
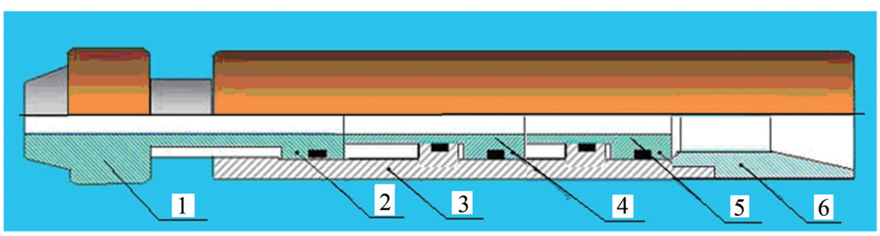


Figure 3
ROP of Compound Drilling Technology with Conventional Drilling

3.3 Rock-Breaking Tools and Down Hole Tools

3.3.1 Hydraulic Thruster

Hydraulic thruster is a new drilling tool, which can convert the liquid pressure energy into drilling pressure by using of circulating pump pressure as a driving force (Lin *et al*., 2003). Changing rigid pressure of drill collar into hydraulic flexible pressure, it can overcome uneven bit feed, bit jumping, fake WOB and other defects. At the same time, the hydraulic pressure device can change the drill string stress state, improve the stability and direction of the drilling tool, so it is conducive to the vertical drilling and can achieve high speed, high quality and low cost drilling purposes. The structural diagram of hydraulic thruster is showed as Figure 4, and application results are showed in Table 2.



1.expansion joint 2.lst class piston 3.cylinder 4.2nd class piston 5.3rd class piston 6.upper joint

Figure 4
Structural Diagram of Hydraulic Thruster

Table 2
Application Effect of Hydraulic Pulse Cavitation Jet

Well	Stratum	Formation section (m)	Average ROP(m/h)	Increased ratio of average ROP compare with the adjacent well without use of hydraulic thruster (%)
LJ-1	J_1z, T_3x	3700~3756.2 4230.57~4424.97 4533~4620.53	0.69	68.29
LJ-3	J_2x, J_2q J_1z, T_3x	284.15~404.69 1827.7~3047	1.14	34
M-2	J_3s, J_2s, J_2x, J_2q, J_1z	392.07~822 2292.9~3266	0.84	48 38
	T_3x ,T_2l	3266~3560	0.56	30
PG-8	J_2s	1666.48~1720	1.49	12.4
PG-9	J_3p, J_3s, J_2s	22.5~243 284~585.8 1420.08~2338.72	1.58 4.5 2.63	11.6 13.06 11.49

3.3.2 Hydraulic Pulse Cavitation Jet

Hydraulic pulsating-cavitation jet compound drilling is a new drilling technology that can make full use of mechanic energy and hydraulic to improve ROP (Li *et al*., 2003). The pulsating-cavitation jet generator is located between bit and screw drilling string. The mechanism of the new drilling technology relies on the combination of high rotating speed of the conventional compound drilling and effectively bottom clearing of the pulsating-cavitation jet to improve ROP (Li *et al*., 2005). Field experiments were conducted in 2 wells of Yuanba area, application effect is showed in Table 3. Application result showed that the hydraulic pulsating-cavitation jet compound drilling could improve the ROP by 30.2%~137.5% percent more than the conventional string drilling.

Table3
Application Effect of Hydraulic Pulse Cavitation Jet

Well	Formation section (m)	Footage (m)	Net drilling time (h)	Average ROP (m/h)	Increasing proportion (%)
Yuanba 12	4100.00~4141.00	41.00	44.49	0.92	30.20
Yuanba 16	3971.51~4028.38	56.87	34.83	1.63	137.5

3.3.3 TorkBuster Torsional Impactor with PDC Bit Drilling Technology

To solve the problem of strong abrasiveness, poor drillability, high pressure gas formations and low ROP in J_2x and J_2q formation, TorkBuster torsional impactor with PDC bit drilling technology was imported, TorkBuster torsional impactor with PDC bit drilling technology can improve well quality and increase ROP through impacting breaking and rotational shearing effect on rock layer. TorkBuster can avoid vibration of drilling bit and translate the fluid energy into torsional and stable impact energy of PDC bit (Guo *et al*., 2012), diagrammatic sketch of TorkBuster torsional impact generator is showed in figure 5. This technology has been applied 8 times in 5 wells in Yuanba area with total footage of 1148.73m and average ROP of 2.40 m/h, and the ROP is the 2.34 times of conventional drilling in the corresponding section(shown in Table 4).Therefore, TorkBuster torsional impact generator can provide an efficient drilling technology for drilling in J_2x and J_2q formation.

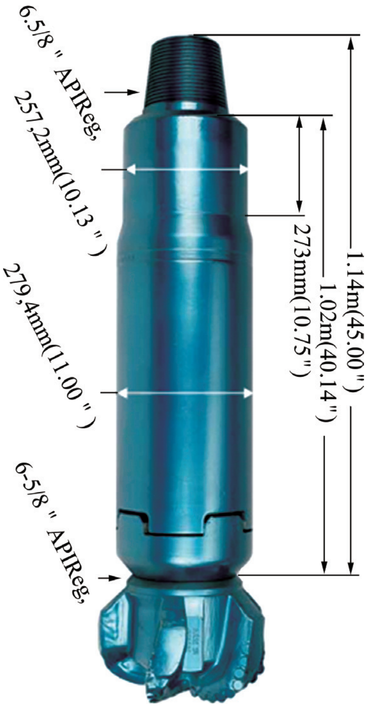


Figure 5
Diagrammatic Sketch TorkBuster Torsional Impact Generator

Table4
Application Effect of TorkBuster Torsional Impactor with PDC Bit

Well	Hole size(mm)	Footage(m)	Formation section	Average ROP(m/h)
Yuanba 10	311.2	270.52	J_2x	3.22
Yuanba 205	311.2	225.7	J_2x	1.9
Yuanba 223	311.2	146	J_2q	2.89
Yuanba 6	311.2	7.62	J_2x	0.54
Yuanba 272H	311.2	506.51	J_2x ~J_2q	2.24
Total		1148.73		2.4

3.3.4 Impregnated Bit with Turbine Motor

Impregnated bit with turbine motor composite drilling technology can make full use of high speed of turbine, high resistance to abrasion and longevity of the impregnated bit comprehensively (Wang *et al*., 2011), which is suitable for high strength formation in J_1z, J_2q and T_3x formation section. Impregnated bit with turbine motor drilling technology has been applied 21 times in 7 wells in Yuanba area with total footage of 3686.23 m and average ROP of 1.34 m/h. Application effect is showed as Figure 8. The application result showed that impregnated bit with turbine motor drilling technology provides a new reference of ROP enhancing for deep well, hard formation and big size hole.

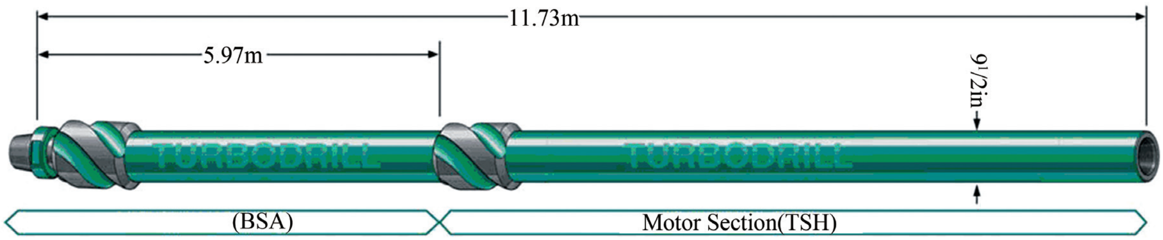


Figure 6
9 1/2″ T1 MK2 Turbodrill

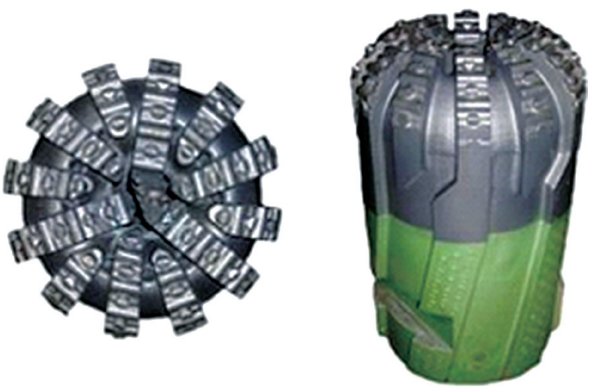


Figure 7
12 1/4″ K705 Bit

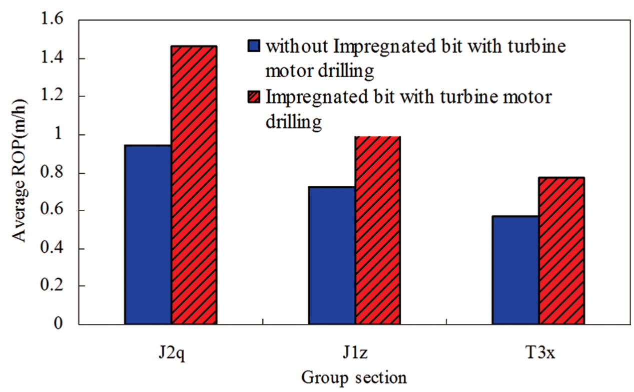


Figure 8
Application Results of Impregnated Bit with Turbine Motor Drilling

3.4 Ultra Deep Well Cementing Technology

3.4.1 An Application of "Dry Cementing" Technique for Large-Sized Casing

To further increase the ROP in Yuanba region and realize gas operation (both drilling and cementing), dry process cementing was practiced in Yuanba 271 well (Φ476.25 mm) based on adequate scientific augmentation. The conductor was set to 702.44m, slurry was injected by 3 times because of large well bore diameter, and the quality of this operation was excellent.

The success of this operation has great significance: Firstly, such procedure optimizes drilling fluid transfer, formation pressure-bearing, accessories penetration, and also avoid the risk of lost circulation, reduce curing time and shorten middle completion interval by at least 6 days. Secondly, dry process cementing ensures the cementing quality because it has no mud cake and displacement efficiency problem. Thirdly, it avoids water absorption and instability of the pocket in conventional cementing, facilitating later gas drilling.

3.4.2 Intermediate and Production Casing Cementing

On the basic of the challenges encountered for Yuanba region and to ensure the quality of cementing, the formation was classified under following categories. They are "3 high and 1 low", "3 small and 1 long" and "2 thick and 1 large".

"3 high and 1 low": The "3 high" refers to high bottom-hole temperature in deep and ultra-deep well (high temperature of 177 ℃ with 7450m depth in Yuanba 3), high formation pressure (with the highest pressure coefficient of 2.15 g/cm^3) and high content of H_2S and CO_2 (individually with the highest content of 268 g/m^3 and 10%), which need the slurry of high quality. The "1 low" refers to the low formation pressure-bearing capacity, causing narrow pressure window and promising channeling and leakage.

"3 small and 1 long": The "3 small" refers to the small clearance between casing(Φ273.1 mm) and the wellbore(Φ311 mm) and the clearance at the collar is 13 mm, the small clearance between casing (Φ193.7 mm) and wellbore(Φ241 mm),the clearance at the collar is 12.5 mm and small clearance between flush joint casing (Φ146 mm) and wellbore (Φ165 mm) is 12.5 mm, which challenge the cementing quality. The "1 long" refers to long open hole, causing contradiction in the coexisted pressure systems, complex slurry structure, and large amount of cement, long work hours and high demand of equipment.

"2 thick and 1 large": The "2 thick" refers to thick cake causes of large amount of bridging material which depress the quality of the second interface and thick salt bed in T_1j formation which require the casing to be both corrosion resistant and salt tolerant. The "1 large" refers to large temperature difference between the upward and downward slurry (with the largest difference of 65 ℃) which is difficult for the slurry to be adaptive.

According to above problems, the following 3 cementing techniques have been applied in Yuanba region by principal study and field application.

(1) Liner hanging and tieback cementing techniques: conventional density and high density slurry system, conventional anti-gas channeling slurry system, Latex anti-gas channeling slurry system, colloidal particle anti-gas channeling slurry system, leak-resisting slurry system , conventional low density slurry system and low density anti-gas channeling slurry system are applied.

(2) Injection with opposite squeeze cementing techniques: mainly used in serious lost circulation sections by balanced pressure cementing.

(3) Small annular clearance cementing techniques in long open hole: mainly used in Intermediate casing cementing.

CONCLUSIONS

(1) Of the completed wells in Yuanba area, the average completion circle is as long as 528.74 d, average middle completion interval is 164.88 d which is 31.2% of the average completion circle, with the average net drilling time of only 36.71%. Drilling speed acceleration of ultra-deep wells in Yuanba region is quite potential if ROP can be accelerated and complexity underlying be decreased.

(2) Under a new round of structural optimization wellbore of Yuanba exploration region, "Φ476.25 mm + Φ339.7 mm + Φ273.1 mm + Φ177.8 mm" structure was introduced, which greatly reduces the complexity and accidents in the drilling process and improve Drilling efficiency.

(3) The drill ability of J1z and T_3x formation is rather poor and bit failure is common in this section. Super abrasive bit should be further developed to increase its life span and avoid frequent trip, so as to increase its ROP.

(4) Dry process cementing reduces the procedures such as drilling fluid transfer, formation pressure-bearing testing, casing accessories, so it reduces middle completion interval, avoids the replacement efficiency problems in the process of common cementing, It should be further studied and promoted.

(5) The integrated technology to increase drilling speed of ultra-deep well has achieved good field application results, which provides a good reference for ultra-deep well drilling.

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