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Drilling Engineering Design of Well WT-1

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Abstract
Well WT-1 is a key exploratory well deployed at Jiangjin district of Chongqing for the exploration of shale gas reservoir with the design depth of 4,900.00 m and designed drilled strata at Ordovician Pagoda formation. Due to the complex situations in this area, there are some technical problems, for example, prediction accuracy of formation pressure is poor, Maokou formation is gas bearing formation with ultra-high pressure, and coal seam and shale bed are easy to collapse. Therefore, the well designing comprehensively adopted conventional casing program design methods, setting position design methods and safety risk assessment technique for casing program design; metal ion polymer drilling fluid system was designed in the upper part, and aluminum amine blocking anti-sloughing drilling fluid system was applied in the lower interval of interest. For well cementing design, conventional cement slurry system was used in the upper part and non-permeable latex channeling preventable slurry system was used in the lower part to improve the quality of cement-formation interface, and two special filter cake curing agents were also used in the design.

Key words: Drilling design; Casing program; WT-1; Setting position; Safety risk assessment

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INTRODUCTION
Well WT-1 is a key exploratory well of Sinopec deployed at Jiangjin district of Chongqing for exploring shale gas reservoir of Longmaxi formation in Silurian system with the design depth of 4,900.00 m and drilled strata at Ordovician Pagoda formation. There is still no well drilling to organic black graptolite shale at the lowermost Longmaxi formation in this the area, therefore, the success of well drilling will provide basis for determining the hydrocarbon source rock potential and reservoir physical property at the bottom of Longmaxi formation, and collecting detailed drilling cost data for future drilling design, it will help to understand the exploration prospect of dark shale at Longmaxi formation in project area, and the drilling data obtained from this exploratory well will help to describe and evaluate Longmaxi black shale's development condition (depth and thickness), shale reservoir properties such as maturity, organic carbon content, clay minerals, porosity, permeability, saturation, gas content, pressure and stress, and so on. Drilling strata is showed in Table 1. Strata pressure prediction is shown in Table 2. The technical problems of the drilling includes: the fractured upper strata has low loading capacity, Longtan formation's coal seam and shale interbedding are easy to collapse, Maokou formation's maximum pressure coefficient is 2.16, as well as high well control risk, high drilling fluid density and low drilling rate. Meanwhile, due to the low degree of prospecting in this area, there are huge differences between the wells in this region, the well has its own characteristic, even couldn't take the adjacent wells for references; there are also many unforeseen factors during drilling.

1. CASING PROGRAM DESIGN

1.1 Determination on Casing Program
The conventional casing program design method is based on three pressure traverses and adopts top-bottom or bottom-top design approach[1]. However, because the pressure system of Well WT-1 drilled strata is complex, strata pressure prediction accuracy is

low, down-hole troublesome conditions during drilling like well kick, leakage, hole sloughing, drilling bit jamming (sticking) of adjacent wells in adjacent areas frequently happened, the casing program designed by the conventional casing program design method couldn't meet the safety requirement of optimal and fast Well WT-1 drilling, the conventional three pressure traverses design approach[1], setting position determination method[2] and safety risk assessment technique[3] shall be used comprehensively to improve the rationality and safety of casing program design. Considering the strata lithology, setting position, strata pressure and other influencing factors, according to the existing data, the stochastic theory method was used to reach the probability density function of down hole complications and to obtain down hole complication location and the possibility, thus proposing targeted casing program design program.

Table 1
Individual-Layer Data Table of Reference Well

Strata Formation	Well WT-1 (Elevation at 247 m) TVD of zone bottom (m)
Lower shaximiao	990
Lianggaoshan	1,075
Da'anzhai	1,116
Ma'anshan	1,263
Dongyuemiao	1,297
Zhenzhuchong	1,450
Xujiahe	1,797
Leikoupo	1,859
Jialingjiang	2,707
Feixianguan+Changxing	3,100
Longtan	3,225
Maokou Qixia	3,663
Liangshan	3,740
Hanjiadian	4,259
Xiaoheba	4,500
Longmaxi	4,850
Ordovician	4,900 (Unfinished)

Table 2
Formation Pressure Prediction Table of Well WT-1

Strata			Drilling fluid density of adjacent well (ppg)		Comprehensive prediction (ppg)
System	Series	Formation	LS~2	LS~1	
Jurassic	Middle system	Shaximiao-lianggaoshan	8.91~10.41	Gas drilling	8.33~9.16
	Lower system	Ziliujing group	Gas drilling		
Triassic	Upper system	Xujiahe			8.33~8.91
	Middle system	Leikoupo	11.83~12.08	10.3~10.5	9.16~11.66
	Lower system	Jialingjiang	11.25~12.83	11.33~12.08	
		Feixianguan, Changxing	13.74~14.16	11.33~11.75	10~13.58
Permian	Upper system	Longtan	14.16~15.74	11.33~13.16	11.58~13.58
	Lower system	Maokou, Qixia	14.66~15.74	12.91~14.41	12.50~17.99
		Liangshan			
Silurian	Upper system	Hanjiadian	13.49~14.66	12.41~13.41	11.66~13.99
	Lower system	Xiaoheba			
		Longmaxi	14.08~14.66	12.25~13.33	
Ordovician	Upper system	Baota			

This well is a exploration well, and with many unexpected factors during drilling, the actual and expected geological conditions may differ to some extent. Troublesome conditions like loss circulation, collapsing and high pressure water zones are possible to exist, and it is also likely to encounter H_2S bearing oil/gas zones. Therefore, during the determination of casing program, the possible variations in formation and pressure shall be taken into consideration, and the selection of casing program shall consider the safety margin of each spud to fulfill the drilling targets. Maokou formation is estimated as one of the major reservoirs from the data of offset Wells L1, L2 and M. Based on the data from this well, the Maximum pressure coefficient of Maokou formation is estimated as 2.16; Longtan formation is an interlayer of coal bed and shale, which is liable to collapsing; therefore, it shall be the main concern of casing program design.

The casing program designed based on the above mentioned conditions and design method is shown in Table 3.

Table 3
Casing Program of Well WT-1

Spud	Drill bit size (in)	Drilling depth (m)	Casing OD (in)	Casing setting depth (m)	Remarks
0	35-3/8	30	28-3/8	30	
1	24	301-701	18-3/4	300~700	
2	16	1,922	13-3/8	1,920	To separate Leikoupo formation, and do not drill gas layer in Jialingjiang formation
3	12-1/4	3,207	10-3/4	3,205	To separate the coal layer of longtan formation and do not drill gas layer of Maokou formation
4	9-1/2	3,762	7-5/8	3,000~3,760	To separate Maokou formation and Liangshan formation
5	6-1/2	4,900	5	4,897	

2. DESIGN OF DRILLING FLUID

2.1 Design Principles

The drilling fluid used should be in favor of rapid and safe drilling, environmental protection, discovery and protection of gas reservoirs, acquisition of geologic data, removing oil and gas, as well as prevention and treatment of borehole problems. Drilling fluid should have good capabilities of anti-collapse, lost circulation prevention, anti-H_2S, anti-high temperature, anti-salt-gypsum contamination as well as protection of gas reservoir. Drilling fluid density should be designed based on the predicted pressure coefficient provided in the Drilling Geologic Design for Well WT-1, actual tested pressure and actual drilling density of adjacent wells as well as wellhead control capability. Focus on discovery and protection of gas reservoirs, ensure balanced drilling and emergency preparedness for well killing.

2.2 Selection of Drilling Fluid System and Density Design

2.2.1 Selection of Drilling Fluid System

Based on the characteristics of the encountered formation, drilling fluid should be featured by anti-salt-gypsum contamination capability, lower filtration rate, good building capacity and lubricity and rheological property, which guarantees safe and rapid drilling. Pay attention to protecting the intervals of interest in the well.

Table 4
Drilling Fluid Types by Sections (Recommended)

Spud sequence	Hole size (inch)	Interval (m)	Recommended drilling fluid system
0	35 3/8	0~30	Metallic-ion polymer drilling fluid
1	24	30~701	Metallic-ion polymer drilling fluid
2	16	701~1,922	Metallic-ion polymer drilling fluid
3	12 1/4	1,922~3,207	Metallic-ion polymer drilling fluid
4	9 1/2	3,207~3,762	Aluminum-amine sealing and anti-collapse drilling fluid
5	6 1/2	3,762~4,900	Aluminum-amine sealing and anti-collapse drilling fluid

2.2.2 Drilling Fluid Density Design

Table 5
Drilling Fluid Density by Sections

Horizon	Bottom depth (m)	Predicted pressure coefficient by Sinopec (ppg)	Designed density (ppg)
Shaximiao Fm.	990		
Lianggaoshan Fm.	1,075	8.33～9.16	8.91~10.41
Ziliujing Fm.	1,450		
Xujiahe Fm.	1,797	8.33～8.91	8.91~10.41
Leikoupo Fm.	1,849	9.16～11.66	9.75~12.91
Jialingjiang Fm.	2,707		
Feixianguan Fm changxing Fm.	3,100	10～13.58	10.58~14.83
Longtan Fm.	3,225	11.58～13.58	12.16~14.83
Maokou Qixia Fm.	3,663	12.50～17.99	13.08~19.24
Liangshan Fm.	3,740		
Hanjiadian	4,259		
Xiaoheba Fm.	4,500	11.66～13.99	12.25~15.74
Longmaxi Fm.	4,850		
Baota Fm.	4,900		

3. CEMENTING DESIGN

There are three key aspects in cementing design, one is the casing material selection, and the second is the cementing method selection, the third is the measure for improving cementing quality of cement-formation interface to solve the annulus pressure problem.

About casing material, conventional low-grade steel casing can not meet the safety requirement due to high strata pressure, so the well mostly used 110-grade steel casing, some used unconventional thick casing, moreover the airtight buckle. According to geological prediction, there is no H_2S in continental strata, Longmaxi formation and Leikoupo, and there was H_2S in other marine strata and there may be good yielding strata in Maokou formation, therefore, the well specifically chose to use anti-sulfur casing in certain well section. The details are showed in Table 6.

Table 6
Datasheet of Casing String Strength Calibration

OD (in)	No.	Interval (m)	Length (m)	Grade	Wall thickness (in)	Thread type	Weight/m (ppf)	Safety factor			Formation pressure factor (sg)
								Tensile strengt (h)	Anti-collapsing	Anti-bursting	
18 3/4	1	0~700	700	N80	12.7	WSP-1T	97.27	12.2	1.79	0.98	1.10
13 3/8	1	0~800	800	110TS	12.19	WSP-NF	68.07	6.05	2.70	0.93	1.40
	2	800~1,920	1,120	110T	12.19	WSP-NF	68.07	9.57	1.25	1.23	
11 1/8	1	0~800	800	110TSS	17.32	WSP-FJ	76.20	2.55	7.90	0.90	1.63
10 3/4	2	800~1,900	1,100	TP110T	13.93	TP-CQ	61.49	4.31	2.73	0.92	
	3	1,900~3,205	1,305	TP110TSS	13.93	TP-NF	61.45	5.27	1.88	1.35	
7 5/8 liner	1	3,000~3,760	760	TP110TSS	12.7	TP-CQ	39.04	8.11	1.01	1.51	2.16
5	1	0~800	800	TP110SS	11.10	TP-CQ	21.42	2.69	6.21	1.44	1.68
	2	800~4,250	3,450	TP110	11.10	TP-CQ	21.42	3.0	1.24	1.72	
	3	4,250~4,550	300	TP110SS	11.10	TP-CQ	21.42	10.4	1.4	5.88	
	4	4,550~4,897	347	TP110	11.10	TP-CQ	21.42	17.6	1.33	6.43	

Cementing methods are selected as per the following principles:

(a) The conventional cementing is adopted by 28 3/8” conductor.

(b) Stab-in cementing is adopted by 18 3/4” mm casing.

(c) 13 3/8” casing adopts stab-in or conventional cementing; if its pressure-bearing capacity is insufficient, stage cementing shall be available with the approval of Sinopec Exploration Southern Company.

(d) 10 3/4” casing adopts conventional bi-setting or multi-setting cementing method; if oil/gas/water are active and the pressure window is narrow, liner cementing firstly, then tieback cementing process shall be recommended.

(e) In 7 5/8” mm liner cementing operation, suspension-release and bi-setting cementing is adopted.

(f) The optimal cementing method for 5” casing is running to bottomhole with one trip as well as conventional multi-setting cementing to ensure the integrity of well bore.

(g) Design on cement slurry system: Conventional cement slurry system is adopted for first spud and second spud. Weighting latex (or colloid particle) non-permeable anti-channeling slurry system is adopted for liners of third spud and fourth spud and casing of fifth spud.

There are many micro-cracks on oil well cement ring, but they couldn’t form connected channel, therefore, there are no fluid channeling generally. The filter cake will cause the incomplete cementing of cement slurry and strata, and the cementing strength is low. If the filter cake is not solidified, it will be detached under the effects of soaking, erosion and others, thus forming fluid channeling passage[4]. Since American Jones and Berdine found residual drilling fluid filter cake could cause the water channeling in 1940, domestic scholars have recognized the importance and complexity of well cement-formation interface, and have conducted long-term exploration, research and practice on this problem, so some technical methods for improving the cementing quality of cement-formation interface have been formed. These methods have been applied at home and abroad for decades and the cementing quality of cement-formation interface and the annulus channeling problem are still quite obvious. Currently, a subsidiary of Sinopec and a university has jointly researched and developed the integrated solidification and cementation of cement-filter cake-strata through filter cake solidifying and interface cross-linking by using filter cake curing agent Ⅰ+ 2 m^3 as the prepad fluid solution and using filter cake curing agent Ⅱ+ 2 m^3 as the prepad fluid solution, which has been successfully applied in three-high gas well drilling in Sichuan. Therefore, the above two curing agents were specially proposed in cementing design of this well to improve the cementing quality of cement-formation interface.

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