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Drilling Engineering Design and Application of Well Fengshen-x601

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ABSTRACT

Thick gypsum and glutenite exist in Fengshen block, which brings a lot of technical problems in drilling construction, therefore, the drilling engineering design optimization of well Fengshen-x601 was launched. Based on the drilling purpose and combined with the actual drilling information of offset wells, the five-intervalled well track and the well structure with four layer casing were adopted in this well, the HJT537GK high efficiency cone bit was recommended in glutenite formation, and saturated saltwater polysulfonate lubricating drilling fluid system was used in gypsum section, through these measures, safety drilling was guaranteed in this well. The average rate of penetration was 3.15 m/h in the actual drilling operation, which increased by 13% compared with the offset wells, in addition, there were no accidents and complex situations. These effective implementation provided some guidance and reference for drilling operations of in the similar block.

Key words: Well track with five-intervalled; Gypsum; Glutenite; Drilling design; Fengshen-x601

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INTRODUCTION

Well Fengshen-x601 locates in Yong an country, ken li county, Dong ying city of Shan dong province. The reservoir of this block is low porosity and low permeability. Thick gypsum and glutenite exist in this block, some problems such as the low ROP and the unstable wellbore in construction affects the effective development of this block[1]. The hydrocarbon reservoir in lower section of Es4 was found during many wells drilling operation in this block, commercial oil and gas flow in lower section of Es4 has been obtained from the offset wells such as Fengshen 1, Fengshen 1-x1, Feng shen 6, Fengshen 10, Yong 938 and Yong 554. In order to explore a drilling and completion matching technology measure to develop this block more efficiently, the drilling design and construction scheme of well Fengshen-x601 were optimized.

1. GEOLOGIC ASPECTS

Well Fengshen-x601 is an evaluation well, of which the purpose is to explore the Es4 sub-salt reservoir of this block effectively and substantially improve the single well flow potential. The formations of this well drilled from top to bottom are Pingyuan, Minghuazhen, Guantao, Dongying and Shahejie group. The actual drilling information of offset wells shows that the formation pressure is “normal - abnormal - normal” distributed longitudinally. A large segment of salt-gypsum rock with buried depth of 3,920 - 4,170 m exists on the top of glutenite reservoir.

2. DRILLING TECHNICAL DIFFICULTIES

(a) Thick gypsum exists on the top of reservoir, which may result in oversized hole by dissolving or tight hole by creeping, and the borehole is unstable.

(b) The bit type selection is difficult and ROP is low because of the poor drillability of glutenite formation. PDC drill bit does not work well in directional drilling, while the cone bit has a short working life which will

lead frequency trips and prolong drilling cycle under the circumstance of deep wellbore, high temperature and high salinity.

(c) It is required to hit the target vertically, and "S" shaped well track with five-intervalled is adopted, which could induce high friction, high pulling torque and key seated hole. In addition, the radius of target area is required to be less than 50m, which is more rigorous than company standard, the well track and wellbore quality are called for strict.

(d) Lost circulation occurs easily due to multiple pressure system and narrow mud weight windows in this block, and it is very difficult to maintain drilling fluid because of the pollution caused by carbanion and bicarbonate radical in lower section of Es3.

3. DRILLING ENGINEERING DESIGN

3.1 Well Track Design

This well, 4,600 m TVD of design and 4,170 m TVD of Target A, is required to hit the target vertically and the radius of target area is required to be less than 50 m. Based on the geologic requirement, the build-up rate in build section should be controlled within 15º/100 m and in drop off interval should be less than 5º/100 m. The well track should be smooth as much as possible as per the requirement of geology. Therefore, five-intervalled type well track (vertical interval - build interval – angle maintaining interval - drop off interval- angle maintaining interval) was adopted in this design. The well track design is shown in Table 1.

Table 1
The Well Track Design of Well Fengshen-x601

MD (m)	Inc (°)	Azi (°)	TVD (m)	V.sec (m)	NS (m)	EW (m)	Dogleg (°/100m)	T.face (°)	Key point
0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	
2,750.00	0.00	146.07	2,750.00	0.00	0.00	0.00	0.00	0.00	Kickoff point
2,976.30	33.94	146.07	2,963.29	65.10	-54.10	36.34	15.00	0.00	
3,659.58	33.94	146.07	3,530.13	446.64	-370.58	249.32	0.00	0.00	
4,338.48	0.00	146.07	4,170.00	641.93	-532.61	358.33	5.00	0.00	Target A
4,768.48	0.00	146.07	4,600.00	641.93	-532.61	358.33	0.00	0.00	

3.2 Casing Program Design

The pressure system and geologic zonation of this well is similar to those of Fengshen 6 and Fengshen 8. The casing program design on the upper section of this well draw lessons from these two wells. Thick gypsum exists in the lower formation and the formation pressure is abnormal high. The oversized hole caused by dissolution of rock salt, pipe stuck caused by salt-gypsum rock creep hole shrinkage, well kick and lost circulation, and so forth. may happen while drilling[2]. Many lost circulation was observed during the salt-gypsum rock formation drilling operation of offset well Fengshen8 and Fengshen10. The glutinite section of formation of interest has a low pressure coefficient and a poor pressure bearing capacity.

Table 2
The Casing Program of Well Fengshen-x601

Spud	Bit size (mm)	Drilling depth (m)	Casing OD (mm)	Casing setting depth (m)	Top of cement (m)
First spud	444.5	0 - 351	339.7	350	Surface
Second spud	311.2	351 – 2,652	244.5	2,650	Surface
Third spud	215.9	2,652 – 4,343	177.8	liner（2,500 - 4,341）	2,500
Fourth spud	149.2	4,343 – 4,768.48	114.3	liner（4,191 - 4,766）	4,191

In order to isolate the complicated intervals and minimize the risk of drilling, the well structure with 4 layer casing was determined after comprehensive consideration of the down hole problems during the offset wells drilling operation, the formation and well track feature of this well. The Φ339.7 mm surface casing shoe seated at 350 m is to isolate the upper unconsolidated formation and establish the well head. The Φ244.5 mm intermediate casing with 2,650 m deep is to isolate the fault in the lower section of Es3 and create favorable conditions for drilling the high pressure zone and gypsum formation. The main function of Φ177.8 mm intermediate liner is to isolate gypsum formation located on the top of the reservoir. Because the bottom of gypsum formation is very close to the top of the reservoir, the intermediate completion zone and depth should be located accurately to avoid lost circulation by drilling out the reservoir. The Φ114.3 mm production liner will be set after reaching the total depth. The casing program is shown in Table 2.

3.3 Matching Technology Optimization

3.3.1 Rig Selection

The design depth of Fengshen-x601 is 4,768.48 m, the vertical depth is 4,600 m, the kickoff point is 2,750 m and the horizontal displacement is 641.93 m. In order to ensure the bearing load and configuration requirements of the rig equipment, 50D type drilling rig was chosen in consideration of geologic environment, drilling technology, wellhead equipment and the drilling ability of dealing with down hole problems.

3.3.2 BHA and Well Track Control Measures

(a) The conventional tapered drill string or pendulum drill assembly is adopted in straight well section, well survey must be conducted at fixed-point, in case of large hole deviation, hole straightening measures should be taken immediately to make sure that the wellbore is straight as far as possible so as to improve wellbore quality and reduce casing wear caused by the drill string in future drilling. There are large borehole and long well section on the vertical well interval of second spud, it is very difficult to carry cuttings, so drilling fluid displacement should be increased to bring the hydraulic cleaning into full play.

(b) The BHA of the buildup and drop off section: drill bit + 1.25° single bend motor assembly + non-magnetic drill collar + MWD + drill collar + HWDP + drill pipe. This well is the five-intervalled directional well track and the kickoff point is deep. When drilling the buildup section, the displacement should be controlled properly and a stable weight on bit and tool face should be guaranteed. Key seated hole occurs easily when drilling the drop off section on the five-intervalled directional well in construction, so it must be broken on time.

3.3.3 Bit Selection

According to the formation features in this block and the actual drilling data of offset wells, soft formations and good drill ability exist on the first spud interval, Dongying and above formations also exhibit a good drill ability so steel tooth bit was selected to increase the ROP in these intervals. After entering the Shahejie group, PDC bit of the large compact combined with torsion impactor was selected to bring the rock-breaking efficiency of PDC bit into full play. There are a large segment of salt-gypsum, glutenite and mudstone interlayer developed on the Es4 section, the bit type selection is difficult owing to the strong abrasivity and solid formations. Refer to the drilling information of offset wells, in glutenite segment of this block the ROP of H517G cone bit is 0.99 m/h. In summary, the high efficiency cone bit of metal seal with dorsal strengthen and special gauge protection structure should be adopted in lower section of Es4[3]. The bit design of well Fengshen-x601 is shown in Table 3.

Table 3
The Bit Design of Well Fengshen-x601

Order number	Formation	Bit size (mm)	Bit type	Number	Well section (m)	Formation lithology
1	Minghua zhen	444.5	P2	1	0 - 351	Clay, bondless sand
2	Dongying	311.2	HAT127	1	351 – 1,435	Mudstone, sandy mudstone, siltstone
3	Es3	311.2	PDC	1	1,435 – 2,652	Mudstone, sandstone、pebbled sandstone, sandy mudstone
4	Es3	215.9	HJT537GK	1	2,652 – 2,976.30	Mudstone, lime mudstone
5	Es4	215.9	PDC	2	2,976.30 – 3,659.58	Mudstone, lime mudstone
6	Es4	215.9	HJT537GK	4	3,659.58 – 4,343	Mudstone, lime mudstone, gypsum
7	Es4	149.2	HJT537GK	5	4,343 – 4,768.48	Glutenite, local mudstone

3.4 Drilling Fluid Design

The main oil-bearing reservoir of this well, locating on the lower section of Es4, is the close grained glutenite, its physical property is poor, and belongs to an extremely low porosity and low permeability reservoir. The drilling fluid is required to present a good reservoir protection ability to prevent solid intrusion and water lock. Due to the long open hole section, the borehole which is easy to collapse, the oversized hole caused by dissolving or tight hole caused by creeping of salt-gypsum, the key to the drilling fluid design is to ensure the borehole stability during drilling operation[4]. Because this five-intervalled directional well track control is difficult, the drilling fluid also should have a good lubricating and anti-sticking ability.

The upper formations of second spud section are weak bonding and easy to slough, the polymer drilling fluid system was adopted to inhibit the formation clay mud-making. The lower Shahejie section is also easy to slough, so it should use polymer anti-caving drilling fluid system. There is a big pressure range above the salt-gypsum of third spud section, lost circulation or well kick is easy to occur in this section due to the narrow mud weight windows, so low-salt polysulfonate lubricating drilling fluid system was selected; because of the dissolution and creep of the salt-gypsum formation, the drilling fluid should have a stable property under salt circumstance and an excellent wall protection ability. Therefore, saturated saltwater polysulfonate lubricating drilling fluid system was used, of which the basic formula is the (4%～5%) bentonite + (0.2%～0.3%) polyacrylamide powder + (2%～3%) sulfomethylated phenolic resin -2 + (2%～3%) sulfonate copolymer fluid loss reducers + (2%～3%) multi-branched phenolic resin -2 + (2%～3%) non-fluorescent white asphalt + 0.5% amine polyol + 0.5% organic silicon fluoride stabilizer + (2.5%～4%) polyalcohol + (25%～28%) industrial salt NaCl. The fourth spud section formation is dense glutenite and the wellbore is stable, so the polysulfonate lubricating drilling fluid system was adopted to improve the ROP and reservoir protection ability, if any falling cuttings was observed, the drilling fluid should be turned into low solids lubrication system and combined with some additives such as corrosion inhibitors, sodium hydroxide used in industry. The drilling fluid design is shown in Table 4.

Table 4
The Drilling Fluid Type of Well Fengshen-x601 Each Well Section

Well section (m)	Formation	Drilling fluid system	Drilling fluid density (g/cm^3)
0 - 351	Pingyuan - Minghuazhen	Bentonite slurry	1.05 - 1.10
351 - 1,435	Minghuazhen - Dongying	Polymer drilling fluid	1.05 - 1.15
1,435 - 2,652	Es1 - Es3	Polymer anti-caving drilling fluid	1.10 - 1.20
2,652 - 3,900	Es3 - Es4 (Before the salt-gypsum)	Low-salt polysulfonate lubricating drilling fluid	1.15 - 1.70
3,900 - 4,343	Es4 (Salt-gypsum segment)	Saturated saltwater polysulfonate lubricating drilling fluid	1.60 - 1.70
4,343 - 4,768.48	Es4 (Glutenite segment)	Polysulfonate lubricating drilling fluid	1.12 - 1.15

3.5 Cementing Design

It is very difficult to make a successful primary cementing operation of Φ244.5 mm intermediate casing because of the long cementing interval. The annulus between Φ215.9 mm bore hole and Φ177.8 mm casing or Φ149.2 mm bore hole and Φ114.3 mm casing is small, thus the friction is big. In addition, the casing string cannot be run into the hole smoothly in salt-gypsum formation because of the tight hole caused by salt-gypsum rock creep. It is very hard to start the pump and make a successful cementing job because the annular pressure loss is too big after the casing is set in place. The cementing quality cannot be guaranteed because of the unstable cement slurry in high bottom-hole temperature. The corresponding measures were taken based on cementing difficulties above-mentioned.

(a) The well track and wellbore quality should be strictly controlled during drilling operation. If tight hole or large degree “dog leg” hole sections are encountered, repeated reaming or short trips shall be conducted to ensure an unrestricted borehole. Circulate fully to remove downhole debris. The tripping-in speed of casing should be controlled within 0.46 m/s. During RIH casing, drilling fluid shall be filled timely as per the requirements. Work casing string up and down while grouting to avoid string sticking.

(d) In order to improve the centralization of the casing strings, ensure the displacement efficiency of cement slurry and improve the cementing quality, elastic centralizers are placed in the straight hole section and the combination of elastic centralizer and rigid centralizer are placed in directional section with 20 - 30 m interval.

(c) Low density fly ash cement slurry system was adopted to prevent loss of circulation and ensure the cementing quality in Φ244.5 mm casing cementation. In Φ177.8 mm casing cementation, saturated saltwater cement slurry with high temperature resistance was used to reduce the influence of salt contamination and high temperature on cement slurry. In order to ensure the displacement efficiency of cement slurry, weighted spacer was designed. In addition, no free water was allowed and API filter loss of cement slurry should be strictly controlled less than 50 mL. The flexibility of cement mantle should be improved to prevent annular fluid migration after fracture[5].

4. THE ACTUAL DRILLING RESULTS

Well Fengshen-x601 spuded in January 21, 2014 and finished well in May 18, 2014. The actual total depth is 4,561.2 m, the vertical depth is 4,398.76 m, the horizontal displacement is 656.04 m and the average ROP is 3.15 m/h. The actual construction was conducted in strict accordance with the casing program design and well track design, the polysulfonated under-saturated saltwater drilling fluid system was used from the MD of 150 m above the predicted thick salt-gypsum, when reaching 50 m above the salt-gypsum, the polysulfonated saturated saltwater drilling fluid system was adopted. The hole diameter enlargement rate of the third spud section was only about 5.21%, which means the hole enlargement and shrinkage was controlled effectively. The HJT537GK high efficiency cone bit was used in glutenite segment, and the ROP reached 0.87 m/h.

CONCLUSION

(a) During the drilling and completion process of well Fengshen-x601, some complex problems were faced including a large segment of salt-gypsum rock, glutenite segment development, the poor drillability, the low rate of penetration, the oversized hole by dissolving or tight hole by creeping of salt-gypsum and the unstable borehole. The bottom hole temperature is high, which affected the performance of drilling fluid, cement slurry and the normal operation of down hole tools. In addition, in this well the kickoff point is deep, it is very difficult to control the five-intervalled directional well track and the casing string cannot be run into the hole smoothly.

(b) The well drilling technology plan suitable for this block was formed through the optimization of well track, well structure, BHA, bit type selection, drilling fluid system and cementing process design. In view of the complex situations that may be encountered, the detailed technical plans were established to ensure the safety and efficiently implementation of this well, it also provided experience and design reference for drilling operation in similar blocks.

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