Well Factory Practice in Bailu Lake Cluster Wells

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Abstract. It is very difficult to economically develop Bailu Lake low permeability reservoir, facing severe anti-collision challenge, as well as trajectory controlling and cuttings carrying of high difficulty, beyond that the reservoir located in the scenic area, where the well site area was limited and the environmental protection requirements were very strict. On the basis of learning the foreign companies’ successful experience on cluster well factory, the authors analyzed the situation and difficulties of Bailu Lake well factory project initially, thus proposing Bailu Lake well factory overall optimized scheme, including slot drilling sequence and trajectory optimization. Through fast rig moving technique, PDC bit and motor optimization and high inhibitive and environment friendly CaCl2 mud system, the rig moving time was shorten by 2 days averagely and one run safe drilling in the second spud. Finally, the total 43 wells were successfully completed, and the average well drilling cycle was shorten by 15.49 days, which had achieved good effects.

Keywords: Cluster wells; factory drilling; drilling practice; low permeability reservoir.

1. Introduction

The well factory technology is an integrated drilling technology, which can cut down the well site land occupation, improve the utilization of equipment and resources, save non-operating time, shorten drilling cycle, and cut down the construction costs. This technology was initially taken into practice in 2008 in North America, and therefore accelerated the shale gas revolution in United States. It is adopted by the domestic and foreign drilling market widely. The American Southwest Energy Co. has applied the well factory technology in the Fayetteville shale gas field[1], and the construction efficiency improved consequently. The application of well factory technology has been extended in the development of unconventional reservoirs, such as tight reservoirs and low permeability reservoirs[2-4]. The well site is narrow and limited because it is located in the Bailu Lake Scenic Area with strict environmental protection requirements. According to the foreign experience and based on the geologic features of low permeability reservoir, the well factory was established in the Bailu Lake area. Through the overall optimization of the drilling program, 43 wells were successfully contrusted. The ROP was greatly increased, and the drilling cycle was shortened effectively by using well factory technology. It has been proved by practice that the well factory technology provided a strong technical support for the efficient development of low permeability reservoirs.

2. Project Overview and Problems While Drilling

2.1. Project Overview

The Bailu Lake well factory project consisted of B37, B644, B647 blocks, and its major reservoir was Shahejie 2~Shahejie 4, which were both low permeability reservoirs, with 7.2 million tons geological reserves. This project included 43 directional wells, with two sections hole structure. If V.SEC>1000m,
Ф444.5мм hole+Ф339.7мм casing was adopted in 1st section; if V.SEC<1000m, Ф346.1мм hole+Ф273.1мм casing was adopted. Ф215.9мм hole+Ф139.7мм casing was adopted in 2nd section for all wells.

2.2. Problems Encountered While Drilling

- There were 12 well of which inclination are below 20°, and thus a lot of controlling work need to be done due to the marked azimuth drift.
- The center to center distance between the subject well and offset well was 5m, and the targets were located in the North-West-South phase, which resulted in great collision risks.
- There were 32 wells of which the open hole MD are above 2000m, in which it was difficult to bring the cuttings.
- There were 27 wells of which the KOP was above 1000m, and the build rate was low in the unconsolidated formation.
- It was difficult to control the trajectory, because the marked change of apparent dip in Shahejie 2 and Shahejie 3 formation, in which the inclination dropped significantly during rotary drilling.

3. Overall Scheme Optimization for the Well Factory

3.1. Rig Organization Optimization

The Bailu Lake well factory covered a long narrow area, about 260m from north to south and 70m from east to west. In this case, the slot was divided into 2 columns, with 22 wells lined in the west and 21 wells lined in the east. To optimize the drilling sequence of the slot, the rig 1 was moved to west column after finishing 12 wells of the east column from north to south, and then the rig 2 was moved to the 10th well of the east column to finish the last 10 wells of the east. Due to the customized organization of rigs, the machine room module, pump room module and mud tank module of the rig 1 was moved only once when finishing 11 wells of the west column.

Figure 1. Drilling scheme of the Bailu Lake well factory.
3.2. Trajectory Optimization

To avoid collision and insure the trajectory quality, the trajectory need to be optimized, which could also reduce the difficulty of drilling and controlling.

The optimization principles:
- The prior section was vertical-build-hold-drop, and the build-up dogleg was 15°/100m.
- The drop-off dogleg was 3°/100m, which was nearly equal to the formation angle dropping rate, in order to boost the ROP.
- The maximum inclination was up to 45°.

For example, the B37-7-X5 well was optimized following these principles, as shown in the Table 1.

### Table 1. The trajectory of B37-3-X5.

| MD (m) | Inc (°) | Azi (°) | TVD (m) | V.Sec (m) | NS (m) | EW (m) | Dogleg (°/100m) | T.face (°) | Target |
|--------|---------|---------|---------|-----------|--------|--------|----------------|-----------|--------|
| 0.00   | 0.00    | 0       | 0.00    | 0.00      | 0.00   | 0.00   | 0.00          | 0.00      | A      |
| 500.00 | 0.00    | 326.90  | 500.00  | 44.68     | 37.43  | -24.40 | 15.00         | 0.00      |        |
| 686.60 | 27.99   | 679.27  | 996.42  | 834.74    | -544.12| 3.00   | 180.00        | A         |        |
| 2714.54| 27.99   | 2470.00 | 1059.33 | 887.44    | -578.47| 3.00   | 180.00        | A         |        |
| 2859.00| 23.66   | 326.90  | 2600.00 | 1059.33   | 887.44 | -578.47| 3.00          | 180.00    |        |

4. Optimal and Fast Well Factory Drilling Technology

4.1. Fast Rig Transporting and Installing Technology

4.1.1. Rig equipment modularization. To satisfy the requirement of hoisting capacity and down hole safety, as well as power mains and rig moving, Bailu Lake well factory need one 40D rig and one 50D rig.

The whole rig set was divided into machine room module, pit module, pump module, solid control module, rig module. Each module was connected by all kinds of pipes and cables. Eventually, 23 wells were contrasted by Rig 1, with only one moving of machine room module, pit module, pump module and solid control module, of which the moving and installing cycle was only 6 hrs.

4.1.2. Rig module fast moving technology. A pawl marching equipment for rig moving was adopted in Bailu Lake well factory, which enabled the rig a long distance move, and it was particularly suitable for moving the rig forward and backward lengthways. The equipment was capable of positioning in the millimeter scale, which was qualified for positioning the rig on top of the embedded conduit accurately. When the rig moves, it only needs to remove the auxiliary equipment that affects the movement of the rig. It does not need to lower the base, derrick and disassemble the drill pipe[5, 6].

The center to center distance between the subject well and offset well in Bailu Lake factory was 5m, it would take 3 days to move the rig in 5m distance without the pawl marching equipment for rig moving, and need 4 cranes, 1 winch car, 2 flatbed trucks. Using this equipment, only 1 crane was needed. The moving time decreased by 2 days and the quantity of automobiles for moving decreased by 75%, in another word the moving cost was sharply cut down.

4.2. Single Run Drilling Technology

The first 3 of the total 43 wells was constructed by 2 runs in the second spud, and the rest 40 wells were all done by single run in the second spud, in which way the drilling efficiency was improved.

4.2.1. Formation Deviating Rule. The second section included 4 parts, which were straight hole, deviating hole, holding hole and dropping hole. Based on the geological date of the Bailu Lake block, the formation characteristics were studied by analyzing the BHA’s deviating performance and the experience of the initial 3 wells, and the summarized rules are as follow:
The Minghuazhen and Guantao are unconsolidated formations, and the dropping rate was 1-3°/100m when rotary drilling. The building rate was 1-3°/100m when rotary drilling in the Dongying and Shahejie 1. It would hold well in the up layer of Shahejie 2, and drop at 1-3°/100m in the lower layer of Shahejie 2 and the Shahejie 3 because of the apparent dip. Therefore the single run drilling technology for Bailu Lake block was established.

4.2.2. Effective Bit Optimization. The HT2465 4 blade PDC bit was run in the second spud, which has big cutter size ($\phi$19mm), and two raw cutters, to realize single run in the second spud with long service time motor[7, 8]. The average ROP was 43.78m/h.

4.2.3. Technical Measures. BHA: $\Phi$215.9mm 4FPDC+$\Phi$172mm 1.25°Moter+$431 \times 410$ Crossover+$411 \times 410$ F/V +$\Phi$127mm NMDP +MWD Sub +$\Phi$127mm HWDP+$\Phi$127mm DP
Drilling parameters: WOB: 20-50kN, Flow rate: 28-32L/s, SPP: 10-15Mpa
Main control measures:
- Strict implementation of the design was needed, and the KOP could be appropriately advanced by 10m in case of unexpected low building rate.
- Building rate at 15°/100m, and no more than 18°/100m while drilling in order to ensure a smooth trajectory.
- The survey interval should be shorten at the main risk depth, to predict the trajectory ahead. The driller should pay close attention to the abrupt change of WOB.

4.3. Drilling Fluid Technology
The formation that Bailu Lake well factory located in, was collapsible and contained much clay. The strong inhibitive ability, excellent lubrication and good performance for borehole stability was called for, and therefore a novel CaCl$_2$ strong inhibition environmental mud system was adopted. The drilling fluid composition is as follow:
- Guantao and upper formation: 4-6% bentonite+0.5% PAM+0.5%Aminopolyol +0.5%CaCl$_2$
- Dongying formation: 4-6% bentonite+0.5% PAM+0.5%Aminopolyol +0.5%CaO+3~5% lubricants
- Shahejie formation: 4-6% bentonite+0.5% PAM+0.5%Aminopolyol +0.5%CaO+1-2% DTJ +3~5% lubricants+(2~3)% high temperature anti-collapse filtrate reducer +(2~3)% low-fluorescence sulfonated asphalt +(2~3)% ultrafine CaCO$_3$

5. Field Application and Promotion
43 wells were completed in the Bailu Lake well factory, 34 wells for Rig 1 and 9 wells for Rig 2. Several problems were encountered during construction, which decreased the ROP and delay the drilling cycle. The problems were solved by immediately summarizing and analyzing. The details are as follow:
- Due to the upper formation characteristics, the second spud of the initial 3 wells were done by 2 runs that a tri-cone bit drilled to the bottom of Dongying then a PDC to TD, which delayed the drilling cycle. After figuring out the formation rules, the following 40 wells were all done by only one run in the second spud.
- The ROP of the 5 blade PDC(HT2565) used in 4th well was low. Using the 4 blade PDC(HT2465) instead, the ROP was boosted enormously.
- The ROP of Rig 2, the 40D rig, was lower than Rig 1, the 50D rig.

The drilling cycle was remarkably boosted by the customized solution, combine with fast rig moving technology and single run drilling technology. The total footage of the Bailu Lake well factory project was 118653m, and the average TD was 2759.37m. The average drilling cycle was 6.26 days and the project was advanced by 15.49 days, which was 71.22 of the planned project cycle.

6. Conclusion and Suggestion
- The well factory drilling technology for large scale cluster wells provides technical support for the development of the low permeability reservoirs, which can boost the ROP, shorten drilling
cycle and cut down the drilling cost significantly.

- It is the key point to apply the effective drilling technology that the overall well factory plan was contemplated.
- A complete set of techniques including fast rig moving, single run drilling, ensured the smooth construction.

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