Discussion on optimization design method for sidetracking wells in Bohai Oilfield

Wang Zhanling¹, Wang Xin*, Liu Liming³, Chen Liqiang¹, Tan Caiyuan², Guo Fang³

¹ CNOOC Ener Tech-Drilling & Production Co., Tianjin, 300459, China;
² CNOOC China Limited-Pengbo Operating Company, Tianjin, 300459, China;
³ State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Cheng Du, 610500, China

*Corresponding author’s e-mail: 13778461848@163.com

Abstract. Sidetracking of inefficient wells in Bohai Oilfield is one of the important means to stabilize production and increase production. Optimizing the sidetracking scheme to achieve cost reduction and efficiency enhancement is the research focus of refined sidetracking well design. In this paper, the theory of sidetracking technologies is introduced and optimization of sidetracking place is given based on the location match of the low-efficient well and the sidetracking well and sidetracking plans in deep and shallow strata is identified. To aim at the shallow sidetracking scheme, the applicable conditions and difficulties are proposed in different cases for reentry technology of marine riser, sidetracking under insulator shoes, surface casing windowing sidetracking, sidetracking under surface casing shoes. Aiming at the deep sidetracking scheme, the optimal flow of the casing sidetracking scheme and sidetracking under production casing shoes is proposed. Taking two low-efficiency wells of A and B in Bohai as an example, the preferred slot and the sidetracking section are preferred, and the sidetracking point is preferred. Finally, the sidetracking location of the two wells is interchanged, and the footage is saved at 1428m. The on-site implementation results show that the two low-efficiency well sidetracking schemes are reasonable and can achieve the purpose of cost reduction and efficiency enhancement. The optimal method of low-efficiency well sidetracking proposed in this paper has certain guiding significance for the sidetracking design of low-efficiency wells in Bohai Oilfield.

1. INTRODUCTION

The development of Bohai Oilfield has gradually entered the semi-late stage, with inefficient wells increasing year by year and high pressure of stable production[1-3]. Different from onshore oilfields, offshore slot resources are limited. Therefore, sidetracking of old wells has become one of the important means to stabilize production and increase production in Bohai Oilfield[4-8]. The statistical results show that the number of old-well sidetrack drilling in Bohai Oilfield has increased year by year in recent three years, accounting for 60%~80% of adjustment well[9-13].

The remaining oil in Bohai Oilfield is mainly distributed among oil wells, at the top of oil layer and near faults. The remaining oil can be effectively tapped by sidetracking the inefficient wells or shut-in wells, which can activate shut-in wells, make full use of the slot resources and effectively enhance oil recovery[14-17]. In general, geological reservoir majors propose the sidetracking well location by...
simulating and analyzing the distribution of residual oil, and use inefficient wells slot to sidetrack to this well location to tap the residual oil.

Faced with a growing number of sidetracking wells, increasingly complicated downhole problems, sidetracking scheme need to be refined to form a technical system, reduce the risk of drilling and completion, and improve the economy of sidetracking of inefficient wells. This paper will systematically introduce the sidetracking well design method in Bohai Oilfield.

2. RELATED WORK

2.1 Analysis of sidetracking status in Bohai Oilfield

From the top to the bottom, the strata of Bohai Oilfield are: The upper and lower sections of the Quaternary, Pliocene and Miocene minghuazhen formation, the Miocene guantao formation, the first, second and third sections of the Oligocene dongying formation, the shahejie formation and the kongdian formation of the Eocene. Among them, the upper part of Minghuazhen formation is interbedded with different thickness of sand and mudstone, and the lower part is thick mudstone with sandstone, mostly contain plastic mudstone. The sandstones and mudstones in the upper Guantao formation are interbedded in different thickness, and the thick sandy gravel in the middle and lower part is intercalated with thin mudstone. The sandstones and mudstones of the first sections and the upper part of the second sections of the dongying formation are interbedded with unequal thickness, most of them contain basalt and tuff. The sandstones and mudstones of the lower part of the second sections and the upper part of the third sections of the dongying formation are interbedded with unequal thickness, and the middle and lower part are mainly composed of thick mudstone, mostly containing diorite porphyry. Shahejie formation is mainly composed of thick mudstone, with bioclastic dolomite developed. The Kongdian formation is developed with a large set of thick layers of gravelly sandstone and glutenite. Granitic gneiss is developed in Archaean buried hill. The main oil-bearing series are located in Minghuazhen formation and Guantao formation.[18-20]

Inefficiency wells in Bohai Oilfield are defined as high water cut wells with production less than 10m$^3$/d whose reservoir flooded due to long-term water injection development, and stripper wells whose production less than 10m$^3$/d caused by engineering reasons (sand production) or geological reasons (poor reservoir physical properties).[7] The main treatment measures for inefficient wells are overhaul, profile control and so on, but these measures cannot effectively exploit the remaining oil, so sidetracking to the remaining oil accumulation area has become an effective means. From figure 1 below, it can be seen that from 2013 to 2019, the number of sidetracking wells in Bohai Oilfield showed an upward trend, and the number of sidetracking wells in 2018 accounted for 82.79% of adjustment Wells. Sidetracking is one of the important ways to achieve stable production in Bohai Oilfield. How to implement sidetracking economically and effectively and develop residual oil is the research focus under the current situation of low oil price. Based on this, sidetracking design should be based on meeting the requirements of geological reservoir, take economy as the main principle and take various factors into consideration comprehensively to achieve optimization of sidetracking scheme and cost reduction and efficiency enhancement.
2.2 General idea of sidetracking design

In general, geological reservoir majors propose the sidetracking well location by simulating and analyzing the distribution of residual oil. The first step of drilling design is to optimize the sidetracking slot according to the position relationship between the current track of the inefficient well and the sidetracking well location, reasonably match the low-efficient well and the sidetracking well location, maximize the use of the old track of the inefficient wells, and reduce the operation difficulty and cost.

Before optimizing the sidetracking section, it is necessary to match the slot with the sidetracking well location. The sidetracking section mainly includes upper well section and lower well section. The sidetracking methods of upper well section mainly includes reentry technology of riser, sidetracking under insulator shoes, surface casing windowing sidetracking, sidetracking under surface casing shoes, while sidetracking methods under lower well section mainly includes the production casing windowing sidetracking and sidetracking under production casing shoes. In the process of drilling design, the selection principle of the sidetracking section is to select the deep sidetracking, make the best use of the old wellbore, reduce the footage and save the cost.

After the selection of the sidetracking section, further optimization of the sidetracking point is required. The optimization of the sidetracking point mainly follows the principles below: making full use of the old wellbore as much as possible to improve the economy of sidetracking; minimizing the engineering risk, especially the risk of collision prevention; avoiding complex formation such as fault, fracture zone and gravel; meeting the requirements of reservoir, completion and oil production; avoiding the centralizer and the casing collar position; selecting well section with good cementing quality[21].

The optimization of the sidetracking point is completed, namely the drilling trajectory design is determined. The follow-up is the conventional drilling design, which will not be described in detail here, and the specific process is shown in figure 2 below.
3. DESIGN METHODS

3.1 Optimization of the sidetracking well slot
Typically, the reservoir discipline proposes a new sidetracking well location according to the remaining oil distribution around the low-efficiency well slot. However, due to the small distance of some wells, the slot and the sidetracking well location proposed by the reservoir discipline may not be the optimal matching. Therefore, in the process of drilling design, it is necessary to make the optimal matching between slot and well location with integrating the trajectory difficulty and footage as well as comprehensively analyzing the position relationship between the released old well slot and the target of sidetracking wells.

3.2 Optimization of windowing section in sidetracking wells
After the sidetracking slot is preferred, that is the corresponding sidetracking well location of low-efficiency well is determined, the next step is to optimize the window killing section. In the process of drilling design, the selection principle of sidetracking section is to select the deep sidetracking first, making the best use of the old wellbore, reducing the footage and saving the cost. At present, the more mature shallow sidetracking scheme in Bohai Oilfield mainly includes reentry technology of riser, sidetracking under insulator shoes, surface casing windowing sidetracking, sidetracking under surface casing shoes. The deep sidetracking scheme mainly includes production casing windowing sidetracking technology and sidetracking under production casing shoes technology.

(1) The riser reentry technology unlike onshore drilling, offshore drilling requires a riser to separate seawater. The so-called riser reentry technology refers to the use of cutting technology to cut and recover the riser, surface casing and intermediate casing at a certain depth below the slit surface, and then re-enter the riser with pretilt tool at the bottom. The features of this technology are as follows: the location of sidetracking well is far from the old well; the old well may have been sidetracked many times, and there is no available well section at the bottom; the cement flowback of inner casing is high, so it is difficult to mill the casing; the hole size after sidetracking is too large. The existing problems are as follows: it is difficult to cut and recycle all the casing and abandon the well; the wellhead stability needs to be further analyzed; since the surrounding well slots have been arranged, the shallow sidetracking may have a greater risk of collision prevention.

(2) The sidetracking under insulator shoes technique. The sidetracking under insulator shoes technique refers to the recovery of all inner casing above the depth of the riser, generally including the surface casing and the technical casing. The cement outside the surface casing generally returns to the...
slit surface, and the cement outside the technical casing generally returns to the surface casing shoes above 100m. Therefore, the difficulty of recovering the casing depends on the return height and cementing quality of the cement outside the casing. If there is no cement outside the casing of the recovery section, it can be directly cut for recovery, and if there is cement outside the casing, it needs to adopt the way of casing milling or milling, which is low efficiency and high cost. The characteristics of this technology are as follows: the location of sidetracking well is generally far from the old well, and the deep sidetracking is more difficult; the technology of Bohai Oilfield is widely used, with high maturity and more operational experience. The existing problems are as follows: for single stage double plugging and some single-stage cementing wells, the difficulty of casing recovery is prominent; the shallow sidetracking may have anti-collision problems.

(3) The surface casing windowing sidetracking technology / The sidetracking under surface casing shoes technology. These two technologies also need to recycle the technical casing in the surface casing to the vicinity of the window cutting point, and the difficulty lies in the casing recovery.

(4) The production / technical casing windowing sidetracking technology. The characteristics of this technology are that the sidetracking well is close to the old well, so the directional well trajectory can be implemented; making full use of the old well to reduce drilling investment. However, its problems are: the hole size is usually small; some completion schemes are difficult to implement; the wellbore integrity problem needs to be considered.

(5) The sidetracking under production casing shoes technology. The production of sand in Bohai Oilfield is more serious, so the reservoir interval is mostly sand control completion. Therefore, the difficulty of the technology lies in the high difficulty of sand control pipe of the old well treatment, long construction period and high cost. However, the sidetracking well is in the same horizon as the development of the old well, and the sidetracking well location is near the old well location, so only the horizontal section is needed for drilling, which can make full use of the old well and reduce the drilling investment. Overall, the cost of the technology has advantages in terms of abandonment and drilling.

3.3 The sidetracking point optimization
The preferred sidetracking point generally based on the production / technical casing windowing sidetracking scheme. If different sidetracking points are selected, the sidetracking track will have different difficulty and the footage will be different. Therefore, it is necessary to optimize the sidetracking point in drilling design to balance task difficulty and cost.

In order to ensure the optimal drilling scheme, the optimal decision tree for sidetracking well design in Bohai Oilfield is formulated, as shown in figure 3 below.
3.4 Sidetracking abandonment design

Different from the new slot drilling design, the sidetracking design process needs to consider the abandonment of the old wellbore. According to the Q/HS 2025-2010 specification of offshore well abandoned, sidetracking can only be carried out after the original wellbore is isolated.

For the shallow sidetracking scheme, the basic flow of well abandonment is that pulling out the original production string, squeezing the cement plug into the target layer to 100m above the top packer, cutting and recovering the upper casing according to the sidetracking scheme, injecting cement plug upward from 30m below the casing cut, which the length of the cement plug shall not be less than 60m.

For the production / technical casing windowing sidetracking scheme, the basic process of well abandonment is to lift the original production string and squeeze cement plug into the target layer to 100m above the top packer.

For sidetracking under production casing shoes scheme, the basic flow of well abandonment is that pulling out the original production string, cutting and recycling the sand control pipe to 30m below the shoes, and squeezing the cement plug to 100m above the upper shoes.

Sidetracking can be carried out after abandoning the old wellbore. The subsequent drilling design is the same as the conventional drilling design, mainly including directional well design, drilling platform seating design, well structure design, drilling fluid design, cementing design, drilling assembly design, bit design, drag and torque as well as hydraulic analysis, logging design, well-control design, oil spill risk analysis, etc., which will not be described in detail here.

4. APPLICATION

In order to effectively utilize the reserves of VIII oil formation and XII oil formation in the lower member of Minghuazhen and improve the development effect, two inefficient wells were used to study the
sidetracking well location based on the study of structure, reservoir, fluid, production performance and residual oil. The casing program of well A was from the water-resistant casing down to 67m, 13-3 / 8 "casing down to 208m, 9-5 / 8" casing down to 2525m, and the well structure of well B was from the water-resistant casing down to 110m, 13-3 / 8 "casing down to 794m, 9-5 / 8" casing down to 3170m. For the low-efficiency well A, the sidetracking location target A1-1 and A1-2 were proposed, and the well A1 is planned to be implemented for the sidetracking; the target B1-1 and B1-2 are proposed for the inefficient well B, and the well B1 is planned to be implemented. The positional relationship between the two inefficient wells A/B well and the sidetracking location target proposed by the reservoir is shown in figure 4 to figure 5 below.

From figure 4 to figure 5, it can be seen that the low-efficiency well A/B is relatively close to the sidetracking well location, so it is impossible to intuitively match the low-efficiency well location with the sidetracking well location. Therefore, in the process of drilling design, the preferred slot should be carried out first, and the inefficient well slot should be matched with the optimal sidetracking well location. In the design process, sidetracking from low-efficiency well A to targets A1-1, A1-2 and B1-1 and B1-2 respectively. See table 1 below for the orbital design results. Then sidetracking from low-efficiency well B to targets A1-1, A1-2 and B1-1 and B1-2 respectively. The orbital design results are shown in table 2 below. It can be seen from table 1 that the inefficient well A can only select the shallow sidetracking scheme regardless of the sidetracking well location A1 or B1, and there is no obvious advantage in comparison between two groups of target trajectories of shallow sidetracking. As can be seen from table 2, deep sidetracking can be achieved by sidetracking A1 well location from inefficient well B to save footage and cost. Deep sidetracking cannot be achieved by sidetracking B1 well location.

Through the above analysis, the shallow sidetracking scheme is adopted for sidetracking well location B1 from inefficient well A, and sidetracking well location A1 from inefficient well B is the deep sidetracking scheme, that is to say, the slot and the sidetracking section are determined.

Further study on the shallow sidetracking scheme is carried out, and comparing the reentry technology of riser and sidetracking under insulator shoes. Due to the sidetracking under insulator shoes scheme needs to casing milling 13-3 / 8 " surface casing during well abandonment, and the cost is relatively high. The overall comparison results show that: the construction period of scheme I is 5 days shorter than that of scheme II, saving 4.3473 million yuan, so it is recommended to reentry technology of riser.

Further research on the deep sidetracking scheme is carried out, that is, the optimization of sidetracking points. It can be seen from schemes 5, 6, 7, and 8 in Table 2 that the deep sidetracking technique is feasible. Considering the task difficulty, completion feasibility and footage comprehensively, and considering that the top depth of the top packer in inefficient well B is 1746m, there should be a certain space between the sidetracking point and the top packer, so the preferred sidetracking point is 1600m.

In summary, sidetracking well location B1 from inefficient well A, namely the scheme 3 in table 1. Sidetracking well location A1 from inefficient well B, namely the scheme 7 in table 2. The total footage of the two wells is 3756m, which saves 1428m footage compared with the total footage of 5184m in scheme 1 and scheme 9 provided by the reservoir scheme.
Fig 4 Relationship between vertical projection and sidetracking location of inefficiency well A/B well

Fig 5 Relationship between horizontal projection and sidetracking location of inefficiency well A/B well

### Tab 1 Orbital design of didetracking A1 and B1 in inefficient well A

| Target | Number | Sidetracking point (m) | Well depth (m) | Length of steady inclined (m) | Footage (m) | Inclination variation (°) | Azimuth variation (°) | Total angular change rate (°/30m) |
|--------|--------|------------------------|---------------|-------------------------------|-------------|---------------------------|----------------------|----------------------------------|
| A1     | 1      | 120                    | 2678          | 1244                          | 2558        | 1.1 → 28.9 → 89.3         | 114.9 → 158.7 → 94.2 | 3.00                             |
|        | 2      | 1400                   | 2778          | 147                           | 1378        | 54.3 → 4.2 → 89.3         | 153.7 → 323.6 → 94.2 | 4.45                             |
| B1     | 3      | 120                    | 2783          | 1320                          | 2663        | 2.1 → 19.3 → 90.2         | 114.9 → 93.0 → 183.2 | 3.00                             |
|        | 4      | 1400                   | 3224          | 75                            | 1824        | 54.3 → 76.4 → 90.2        | 153.7 → 3.7 → 183.2  | 6.09                             |

### Tab 2 Orbital design of didetracking A1 and B1 in inefficient well B

| Target | Number | Sidetracking point (m) | Well depth (m) | Length of steady inclined (m) | Footage (m) | Inclination variation (°) | Azimuth variation (°) | Total angular change rate (°/30m) |
|--------|--------|------------------------|---------------|-------------------------------|-------------|---------------------------|----------------------|----------------------------------|
| A1     | 5      | 150                    | 2684          | 1213.05                        | 2534        | 0.21 → 29.48 → 89.3       | 155.34 → 158.29 → 94.21 | 3.00                             |
|        | 6      | 1500                   | 2702          | 82.87                          | 1202        | 30.63 → 28.73 → 89.3      | 155.83 → 166.87 → 94.21 | 3.03                             |
|        | 7      | 1600                   | 2695          | 106.53                         | 1093        | 31.42 → 30.82 → 89.3      | 156.64 → 155.86 → 94.21 | 3.13                             |
|        | 8      | 1700                   | 2694          | 12.80                          | 994         | 32.04 → 32.60 → 89.3      | 156.44 → 148.39 → 94.21 | 3.14                             |
| B1     | 9      | 150                    | 2776          | 1244                          | 2626        | 0.2 → 19.4 → 90.2         | 155.3 → 92.0 → 183.2   | 3.00                             |
|        | 10     | 1500                   | 2749          | 318                           | 1249        | 30.6 → 38.0 → 90.2        | 155.8 → 50.8 → 183.2   | 9.20                             |

### Tab 3 Optimization of shallow sidetracking scheme

| Scheme name | The shallow sidetracking scheme | The sidetracking point (m) | The drilling period (d) | Well abandonment period (d) | Well abandonment cost (Ten thousand yuan) | The drilling cost (Ten thousand yuan) | Amount (Ten thousand yuan) |
|-------------|---------------------------------|-----------------------------|-------------------------|----------------------------|-------------------------------------------|---------------------------------------|----------------------------|
| Scheme 1    | Reentry technology of riser     | 10.0                        | 13.0                    | 1065.58                    | 2470.43                                   |                                       | 3536.01                    |
| Scheme 2    | Casing milling 13-3/8" sidetracking casing | 120                      | 16.0                    | 1609.22                    | 2252.46                                   |                                       | 3861.68                    |
5. CONCLUSION

(1) The remaining oil can be effectively tapped by sidetracking the inefficient wells, which can activate inefficient wells, make full use of the slot resources and effectively enhance oil recovery.

(2) This paper proposes the optimization method for sidetracking wells in Bohai Oilfield from the perspective of the preferred slot, the preferred sidetracking section and the sidetracking point, and established the optimal decision tree model for sidetracking well design in Bohai Oilfield, which is convenient to guide sidetracking scheme design.

(3) Taking two low-efficiency wells of A and B in Bohai as an example, the preferred slot and the sidetracking section are preferred, and the sidetracking point is preferred. Finally, the sidetracking location of the two wells is interchanged, and the footage is saved at 1428m.

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