Energy Proceedings
Vol 54, 2025
ISSN 2004-2965

Research on the water control strategy of intelligent sliding sleeves in horizontal well#

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ABSTRACT

The intelligent water control sleeve can measure water cut and flow rate in real-time, remotely control the sleeve opening, and adjust the flow rate from different formation segments into the wellbore. To enhance the water control efficiency of the intelligent sliding sleeve, a multi-segment well reservoir model was established based on Well A01H in the M oilfield of the Bohai Sea. Reservoir numerical simulations were conducted for the water control process during the water-free period, low and medium water cut period, and high water cut period to study the adjustment strategies for the intelligent sliding sleeve valve opening. The results indicate that during the water-free period, targeting the liquid production profile, the duration of water-free oil production can be extended by reducing the sleeve valve opening in high production sections and increasing the opening in low production sections. During the low to medium water cut periods, with water cut as the control target, the rate of water cut increase can be reduced by decreasing the sleeve valve opening in high water cut sections and increasing the opening in low water cut sections. In the high water cut period, the focus shifts to maximizing daily oil production. Cumulative oil production can be increased by further extracting liquid production within the permissible range of production pressure difference. This study proposes control objectives and methods for each stage of intelligent sliding sleeve adjustment in horizontal wells, providing theoretical and practical guidance for water control development in CNOOC oilfields.

Keywords: Intelligent sliding sleeve, Horizontal well, Water control and enhanced oil recovery, Multi-segment well model, Reservoir numerical simulation

1. INTRODUCTION

In the development of edge and bottom water reservoirs, horizontal wells have a larger drainage area and higher production compared to vertical wells, and have been widely used with significant development results. However, some serious issues have been exposed. Due to factors such as reservoir heterogeneity, distance to edge and bottom water, and heel-toe effect, the liquid production profile along the horizontal wellbore is uneven, leading to problems like local water coning, which severely affects the development effectiveness of horizontal wells [1-3].

To address the problem of local water coning in horizontal wells with edge and bottom water, decades of research have led to the development of passive inflow control devices (ICDs), autonomous inflow control devices (AICDs), and inflow control valves (ICVs). These water control devices are installed between the reservoir and the wellbore to create additional pressure drops as reservoir fluids enter the wellbore, thereby balancing the uneven liquid production profile and achieving effective water control. Based on the principle of generating additional pressure drops, ICDs can be further divided into three types: choke-type ICDs [4], friction-type ICDs [5], and hybrid-type ICDs [6]. These ICDs are installed during the completion of new wells, and the additional pressure drop generally increases with the daily liquid production rate, thus classified as passive ICDs. AICDs [7,8] not only have additional pressure drops related to flow rate, but also decrease the additional pressure drop as viscosity (water cut) increases, which helps improve the water control effectiveness in horizontal wells [9-12]. ICVs [13,14] can remotely adjust the sliding sleeve opening degree from the surface to freely control the flow rate entering the wellbore from the formation, enhancing water control effectiveness and are gradually being implemented in offshore oilfields in China [15,16].

This is a paper for the 16th International Conference on Applied Energy (ICAE2024), Sep. 1-5, 2024, Niigata, Japan.

With the development of flow meters and water cut sensors, ICVs have evolved into truly intelligent water control valves, capable of adjusting formation flow rates based on changes in water cut. Additionally, due to the ability to adjust valve opening degree through sliding sleeves, these are also referred to as intelligent sliding sleeves (ISS) for water control in Chinese offshore oilfields. As the technology of intelligent sliding sleeves for water control is gradually applied in offshore oilfields, there is an urgent need to study the methods of adjusting the opening degree of intelligent sliding sleeves and their water control effectiveness. Therefore, this paper takes the Bohai Oilfield in China as an example to compare the water control process of ICDs and study the control strategies of intelligent sliding sleeves, aiming to improve the water control development effectiveness of horizontal wells in Chinese offshore oilfields.

2. RESERVOIRS NUMERICAL SIMULATION METHOD FOR MULTISTAGE WELLS IN OIL RESERVOIRS

2.1 Multistage Well Model for Water Control in the Horizontal Well

Water control production in horizontal well is a continuously evolving process. The water control valve can adjust the flow rate from the reservoir into the wellbore by adding a pressure drop, achieving a relatively balanced production profile along the horizontal well. The water control completion for horizontal wells can be realized through the multi-segment well model in reservoir simulation software. Sand and water control open-hole completion is employed in the Bohai M oilfield, utilizing an expandable packer for segmenting, and gravel packing is conducted in the annulus outside the screen. The base pipe of the water control screen is connected to the production tubing, and the ICDs are set inside the water control screen. The annulus fluid can only enter the production tubing through the ICDs. As shown in Figure 1, there are the four flow processes: the flow between reservoir grids, the flow from the wellbore grid into the well, flow through the water control valve, and the flow along the wellbore with flow directions indicated by arrows.

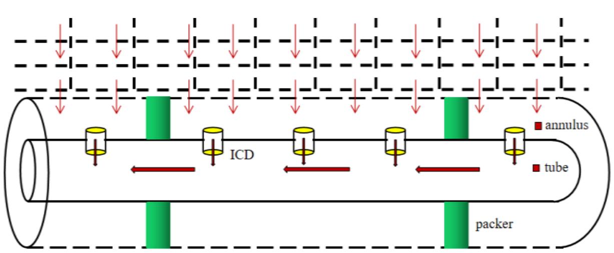

Fig. 1 Schematic Diagram of the Multi-segment Well Model for Water Control in Horizontal Well

Due to structural and dimensional limitations, the intelligent sliding sleeve cannot be directly installed on the water control screen. Therefore, an additional set of tubing is added inside the base pipe of the screen as the water control tubing string. The packers are set outside the tubing in sections, with positions matching the packer positions outside the screen. The annulus inside the screen is connected with the annulus inside the tubing. From the perspective of the multistage well model, these can be combined, and the multistage well features are similar to those in Figure 1, with multiple ICD structures combined into one intelligent water control sliding sleeve.

2.2 A01H Reservoir Model in Bohai M Oilfield

The Bohai M oilfield is located in the central Bohai region, characterized by a faulted anticline structure. The oil-bearing intervals are the Mingxiazhen and Guantao formations, with significant permeability differences in the fluvial facies sedimentary horizontal sections. Water flooding is easy to occur when the wellbore of horizontal well is close to water layer and high permeability layer. Initially, directional wells with multilayer commingled production were used, resulting in severe interlayer interference. Recently, intelligent sliding sleeves for water control in horizontal wells have been employed. As shown in Figure 2, the horizontal well called A01H is belonged an edge water-driven reservoir. The reservoir model of A01H well is extracted from the overall reservoir model, with the A03 well serving as the water injection well, retaining the original injection-production characteristics. The formation depth of the A01H well is approximately 1232 meters, with a total reservoir thickness of about 14.04 meters, an average porosity of 28.0%, and an average horizontal permeability near the wellbore of 1700 mD. The underground crude oil viscosity is 97.5 cp. The well A01H is 301 meters long, with higher permeability towards the mid-toe direction,

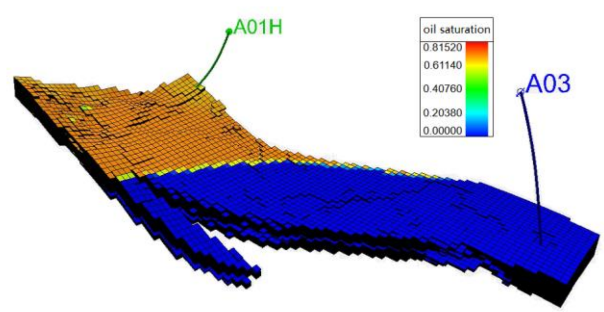

Fig. 2 Distribution Characteristics of Oil Saturation Driven by Edge Water in the A01H Well

and a permeability contrast of 2.5. The edge water and wellbore are relatively parallel, with the edge water front already invading the bottom of the horizontal well, and the water saturation at the bottom of the horizontal well approaching 50%.

2.3 Segmented Water Control Scheme for the A01H Well

A numerical simulation of the reservoir without water control for the A01H well was conducted, setting a daily oil production rate of 50 m³/d and a maximum daily liquid production limit of 650 m³/d. Using the Petrel software, a numerical simulation of the reservoir was performed over 10 years. Based on the 9-point grid method, the maximum production pressure difference was 1.05 MPa, with cumulative oil production of 107,600m³ and cumulative water production of 1,983,300 m³. The water-free oil production period was short, and the water cut increased rapidly, indicating severe water invasion, necessitating segmented water control to improve development efficiency. Based on the numerical simulation results, a profile of daily liquid production and water cut was plotted. As shown in Figure 3, the A01H well is divided into 10 segments along the horizontal wellbore, each segment being 30.1 meters long. Segments 4-8 have the highest daily liquid production and water cut, designated as the water control segments, while segments 9-10 have the lowest daily liquid production and water cut, designated as the stable oil segments, and segments 1-3 have moderate daily liquid production and water cut, designated as one segment.

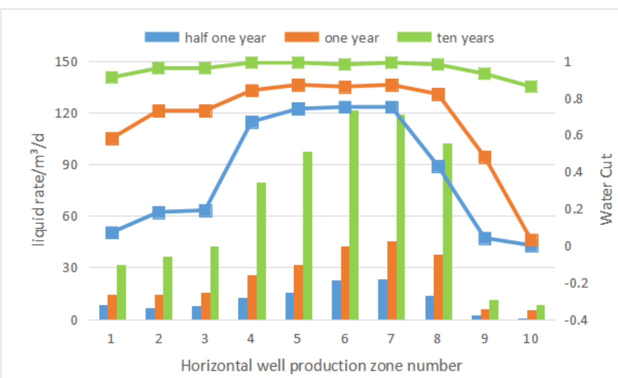

Fig. 3 Production Profile Characteristics of A01H Well Without Water Control

3. RESULTS AND ANALYSIS OF INTELLIGENT SLIDING SLEEVE WATER CONTROL

A reservoir numerical simulation was conducted using ICD to analyze the water control process. Based on the water control problems of ICD, the opening of the intelligent sliding sleeve water is carried out, and the water control strategies for intelligent sliding sleeve were studied.

3.1 Water Control Effectiveness and Problems of ICD

Considering the uncertainty of reservoir model parameters, ICDs were uniformly installed at intervals of 10 meters along the production section. Through trial calculations, it was ensured that the production pressure differential at the end of daily liquid increaing was controlled at twice the level without water control. The production characteristics were statistically compared to evaluate the effectiveness of ICDs in enhancing oil production and controlling water. As shown in Table 1, over a period of 10 years, the cumulative water output decrease was 24,800 m³, with a decrease rate of 1.25%, and the cumulative oil increase was 4,400 m³, with an increase rate of 4.08%.

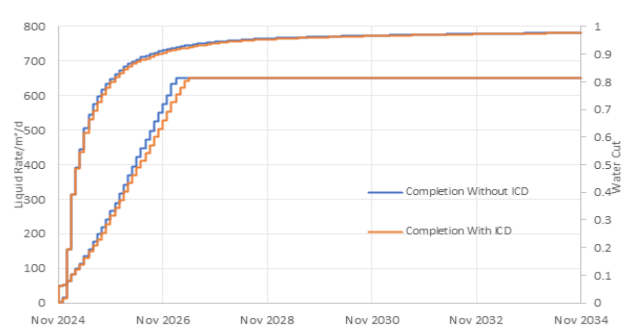

Fig. 4 Comparison of Water Control Effectiveness of ICD Completion

Table 1: Comparison of Production Characteristics between ICD and no water control

Water Control	Water Control Scheme	Pressure Differential (MPa)	Production Time (years)	Cumulative Oil Output (10km³)	Cumulative Water Output (10km³)
No control		1.05	10	10.76	198.33
ICD	Uniform	2.10	10	11.20	195.85

Based on reservoir numerical simulation results, the water cut characteristics of ICD and no water control were compared to analyze the effectiveness and problems of ICD. As shown in Figure 6, the water-free oil production time for both ICD and no water control was the same at 1 month. The production period with continuously increasing daily liquid output is 15 months for no water control and 19 months for ICD. During the initial stages of fixed oil production and daily liquid increaing production, the water cut curve for ICD closely overlapped with that of no water control, indicating no water control effectiveness. However, in the middle and later stages of liquid increasing production, the water control effectiveness of ICD gradually became evident as the daily liquid production increased.

At different production stages, the effectiveness of ICD water control is related to changes in daily liquid production and production pressure differential. As shown in Figure 5, during the water-free oil production period and the initial stage of liquid increasing production, the production pressure differential with ICD overlapped with that of no water control, indicating that ICD did not produce a valve pressure drop and had no water control effect when daily liquid production was low and. As daily liquid increased, The production pressure differential with the ICD gradually exceeded that of the non-water control, resulting in a valve pressure drop and initiating water control.

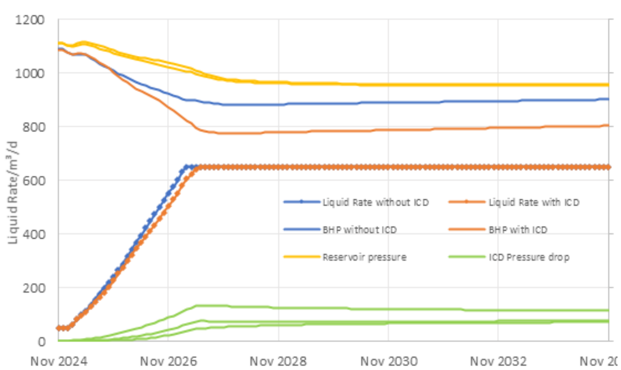

Fig. 5 Production Pressure Differential and Valve Pressure Drop of ICD

In summary, the water control effect of ICD is mainly reflected in the middle and later stages of liquid increasing production and the stable production period. ICD valves can produce sufficient water control pressure drop and regulate the liquid production profile along horizontal well. Figure 6 shows the production profile characteristics after one year. As shown in Figure 6, the daily liquid production in the second segment (water control segment 4-8) significantly decreased, while the daily liquid production in the third segment (oil increase segment 9-10) and the first segment (1-3 low water cut segments) significantly increased, demonstrating a noticeable water control and oil enhancement effect of ICD. However, further observation of water cut variation characteristics reveals that the water cut in the third segment remains much lower than in the second segment, indicating that while ICD can adjust the liquid production profile based on liquid volume, it cannot further adjust the liquid production profile based on water cut characteristics.

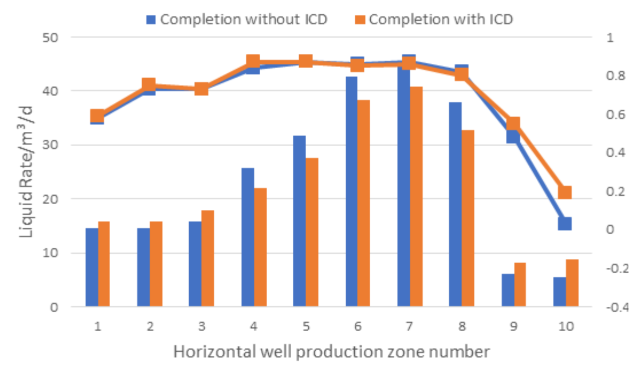

Fig. 6 Production Profile Adjustment Effect of ICD

3.2 Study of Intelligent Sliding Sleeve Water Control Strategies

The intelligent sliding sleeve can measure water cut and daily liquid production in real-time and remotely control the sleeve opening. It can produce a valve pressure drop during the water-free oil production period and the initial stage of daily liquid increaing production, and adjust the liquid production according to water cut characteristics during the middle and later stages of production, achieving effective water control and oil enhancement in all production stages of horizontal well. By determining the sleeve opening at each stage through trial calculations and statistically comparing the production characteristics, the effects of water control and oil enhancement were evaluated. As shown in Table 2, over a period of 10 years, the cumulative water volume was decreased 53.4 km³, representing a water decrease rate of 5.34%, and the cumulative oil was increased 6,500 m³, with an oil increase rate of 6.0%. Compared to ICD, the intelligent sliding sleeve demonstrated a significant improvement in water control and oil enhancement, with a 115% increase in water control volume and a 48% increase in oil production.

Table 2: Comparison of Production Characteristics between ICD and no water control

Water Control Method	Water Control Scheme	Pressure Differential (MPa)	Production Time (years)	Cumulative Oil Output (10km³)	Cumulative Water Output (10km³)
ICD		1.05	10	10.76	198.33
ISS	Uniform	2.40	10	11.41	192.99

Based on reservoir numerical simulation results, the water cut characteristics of Intelligent slide sleeve and no water control were compared to analyze the water control effect of the intelligent sliding sleeve. As shown in Figure 7, the intelligent sliding sleeve demonstrated effective water control during the water-free oil production period, liquid increasing production period, and high water cut stable production period. The water-free oil production period with the intelligent sliding sleeve extended to 3 months, and the daily liquid increasing production period extended to 21 months, compared to 2 months and 6 months increases respectively for no water control completion.

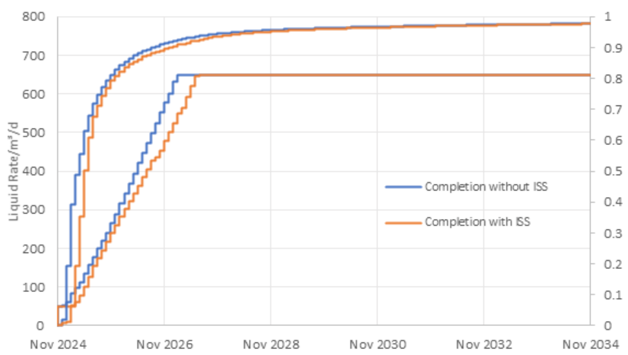

Fig. 7 Effectiveness of Intelligent Sliding Sleeve Water Control Completion

At different production stages, the intelligent sliding sleeve can adjust its opening according to changes in daily liquid production and water cut. As shown in Figure 8, during the water-free oil production period and the initial stage of daily liquid increasing production, the production pressure differential with the intelligent sliding sleeve exceeded that of no water control, indicating effective pressure drop generation. As daily liquid increasing increased, the intelligent sliding sleeve gradually reduced the opening to maintain consistent production pressure, and the valve pressure drop did not increase with daily liquid production. After the daily liquid increasing production ended, the sleeve opening remained relatively unchanged, maintaining stable production.

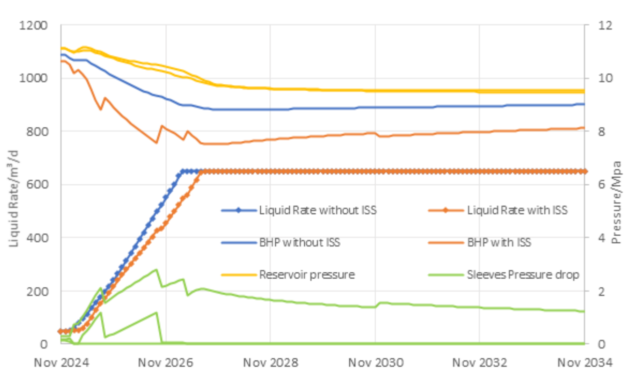

Fig. 8 Production Pressure Differential and Pressure Drop of Intelligent Sliding Sleeve

As shown in Figure 9, it is evident that the daily liquid production in the second segment (water control section 4-8) significantly decreased, while the daily liquid production in the third segment (oil increase section 9-10) substantially increased, and the first segment (1-3) also saw a noticeable rise. The water cut across the segments was adjusted from the significant disparities observed in the no water control to a relatively balanced state, fully achieving the uniform water production characteristic of the horizontal well. This maximized the water control and oil enhancement effects.

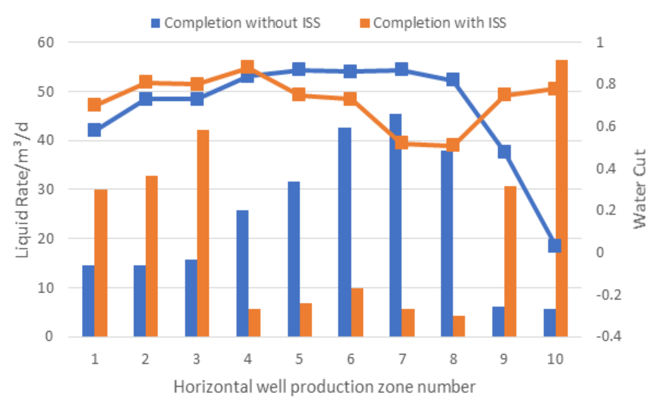

Fig. 9 Adjustment Effect of Production Profile with Intelligent Sliding Sleeve

4. CONCLUSIONS

By analyzing the issues associated with ICD and designing an intelligent sliding sleeve for water control, an intelligent sliding sleeve control strategy was established, achieving effective water control and oil enhancement. The main findings are as follows:

(1) The intelligent sliding sleeve can generate sufficient additional pressure drop by maintaining a small sleeve opening during the water-free oil production period and the initial stage of increasing daily liquid production. This effectively extends the water-free oil production period and the low water cut production period.

(2) After water breakthrough in horizontal wells, adjusting the sleeve opening based on water cut can effectively reduce the overall water cut, extend the fixed oil daily liquid increasing production time, and improve water control and oil enhancement effects.

(3) During the high water cut stable production stage, after the daily liquid increasing production ends, maintaining a constant valve opening in each segment continues to provide an oil enhancement effect.

REFERENCE

[1] Yu Cuiling, Lin Chengyan. Advancement of reservoir heterogeneity research [J]. Petroleum Geology and Recovery Efficiency, 2007, (04), 15.

[2] Hu Donghui, Ni Jienian. The influencing factors of horizontal well productivity [J]. Petroleum Exploration and Development, 1994(05):44-52+119-120.

[3] V.M. BirchenkoK.M. MuradovD.R. Davies. Reduction of the horizontal well's heel-toe effect with inflow control devices[J]. Journal of Petroleum Science & Engineering, 2010, 75(1a2).

[4] Vela I, Viloria-Gomez LA, Caicedo R, et al. Well production enhancement results with inflow control device (ICD) completions in horizontal wells in Ecuador [R]. SPE 143431, 2011.

[5] Aadnoy BS, Hareland G. Analysis of inflow control devices [R]. SPE 122824, 2009.

[6] Brekke K, Lien SC. New and simple completion methods for horizontal wells improve production performance in high-permeability thin oil zones [R]. SPE 24762, 1994.

[7] Vidar Mathiesen, Haavard Aakre, Bjornar Werswick, et al. The autonomous RCP valve-new technology for inflow control in horizontal wells [R]. SPE 145737, 2011.

[8] Least B, Greci S, Burkey R, et al. Autonomous ICD Single Phase Testing; proceedings of the SPE Annual Technical Conference and Exhibition, F, 2012 [C]. SPE-160165-MS.

[9] Luo Wei, Lin Yongmao, Li Haitao, et al. ICD completion optimization design of horizontal wells in heterogeneous bottom-water reservoirs [J]. Acta Petrolei Sinica, 2017, 38(10):1200-1209.

[10] Wang Lijun, Li Chuangang, Wangbingang, et al. Status and Development Trend of Horizontal Well Water-control Completion Technology for Offshore Oil Field. [J]. Oil Field Equipment,2017,46(01):86-89.

[11] Zhang Qilong, Gong Ning, Xu Gang.et al. Design of ICD water control scheme and evaluation method in Bohai Oilfield. [J]. Well Testing,2019,28(02):61-67

[12] Li Junbao, Han Yaotu, Lin Jiayu, et al. Research and Application of Water Control Technology in Bohai Oilfield [J]. Unconventional Oil & Gas, 2017, 4(01):75-78.

[13] Marwan Zarea, Saudi Aramco, Ding Zhu. An integrated performance model for multilateral wells equipped with inflow control valves [R]. SPE 142373, 2011.

[14] Haavard Aakre, Britt Halvorsen, Bjornar Werswick, et al. Smart well with autonomous inflow control valve technology [R]. SPE 164348-MS, 2013.

[15] Bi Chuang, Liu Wei, Sun Li, et al. Research and application of subdivided and intelligent completion technology for offshore horizontal open-hole wells [J]. China Petroleum Machinery, 2024, 52(3): 10-17.

[16] Guo Minglong, Li Jin, Qi Yanlai, et al. Hydraulic control intelligent separate zone production technology and its application in Bohai oilfield [J]. China Petroleum Machinery, 2023, 51(11): 138-143.