Application of binary compound water control technology in the development of horizontal wells in offshore oil fields

Yigang Liu 1, Yunbao Zhang 1, Baoqing Xue 1, Yikuan Lu 1, Jia Wang 2, Jian Zhou 2,3 Tongjing Liu 2, *

1 Tianjin Branch of CNOOC (China) Ltd. Tianjin, China
2 The Unconventional Oil and Gas Institute, China University of Petroleum, Beijing, China
3 Beijing Jinshiliyuan Technology Co. Ltd., Beijing, China

*Corresponding author e-mail: ltjcup@cup.edu.cn

Abstract. Offshore A oil field is a typical bottom water reservoir with thin thickness of oil layer and large thickness ratio of water layer and oil layer. Due to its strong bottom water energy, serious non-homogenous and the impact of the bottom ridge, most of the horizontal well production segment is seriously water out. Based on interaction relationship between horizontal segment trajectory and oil and-water interface, the distribution and contrast of permeability along horizontal segment and the comprehensive analysis of production performance, this paper combines the characteristics of the residual oil distribution of typical wells and the mechanism of dual compound oil addition, and from the perspective of combining theory with the field creatively put forward the dual composite water control mode of first injecting gel segment plug and then injecting foam. Then completed the design of dual compound water control mode and dosage of the typical well. After processing water control measures, the production data shows that the water content decreased significantly after opening the well, from 95.1% before water control to 80%, which was 15% lower. Also the oil production rate has a significant increase from 2.3t/d before water control to maximum of 9t/d after implementing control measures and cumulative oil increase is 550t with effective period of 135 days. The effect of oil and precipitation is obvious.

1. Introduction
Horizontal well is one of the most effective ways to develop bottom water reservoirs. Since the 1990s, the rapid development of horizontal well technology has provided new ideas and methods for the economical and effective development of bottom water reservoir [1-4]. Horizontal wells increase the length of the wellbore in the production layer and the oil leakage area of the production layer and can develop reservoirs under low pressure difference, improve crack drilling rate and effectively solve the oil and gas field development process, such as fluid problems, that is, water (gas) cone control, and reservoir problem, that is, thin layer, low permeable dense reservoir, natural crack reservoir, thick oil reservoir development, achieves the goal of "high yield of thin wells"[5-8]. However, in the actual production of oil fields, due to the strong energy of the bottom water, the horizontal section of the non-homogenous serious and other factors, the bottom of the bottom water reservoir horizontal well ridge...
into is a very serious problem. Its appearance will significantly reduce oil production, so how to control or at least mitigate the bottom ridge is an important issue facing the production unit [9]. Because the combination of horizontal well development and geological understanding is difficult, dynamic and dynamic mutual promotion is not close, it is easy to lead to the development of dynamic evaluation difficult, on-site water control measures targeted is not strong, stable production and poor yield production effect. With the rise of water content, the scale of production increase measures such as horizontal well water control is carried out, which puts forward higher requirements for the identification of the law of horizontal well flooding and the design of water control scheme [10-12]. Based on the relationship between horizontal segment trajectory and oil-water interface, the differential penetration distribution along the horizontal segment and the very poor permeability, and the comprehensive analysis of production dynamics, combined with the characteristics of the residual oil distribution of typical wells and the mechanism of binary compound oil-raising, the binary compound water control mode is creatively proposed from the perspective of combining theory and field. It provides theoretical guidance and mine application experience for water-controlled water control at level of reservoir similar to bottom water reservoir.

2. Production status of target horizontal wells and water control technology design

2.1. Overview of reservoirs in research areas
Offshore A oil field reservoir buried depth of about 1850 to 2200m, for a low-volume broken slope by the structure-controlled sandstone pore-type underwater unsaturated reservoir, the average reservoir thickness of 15m, water oil thickness ratio of 6; The mezzanine is sporadically developed, the space spread range is small, the average porosity is about 22%, the average permeability is $900 \times 10^{-3}$ μm$^2$, and the vertical penetration is high, the vertical horizontal ratio is 1:2.2, while the reservoir permeability is high, the inner stage difference is more than 30, its driving type is mainly the bottom water drive, the bottom water energy is sufficient, The volume ratio of water oil is greater than 60, followed by elastic drive.

2.2. Analysis of the water outing characteristics and residual oil in the target well
A-101H well is a horizontal well in the A oil field, completed drilling and put into operation in July 2002, finished drilling depth of 1574.97m (deep), finished the well for the cut lining pipe completion, the production well section is 1849.42 to 2235.23m.

   (1) Reservoir features
   The A-101H well is in the middle of the north-west wing of the back-slope structure. Horizontal segment 401.00m, oil layer thickness 15.5m, water-avoidance height of 10.7m; production well segment average permeability of 313.1md, permeability is jagged distribution; maximum permeability 1569.0md, minimum permeability 0.1md, permeability difference 3.61; High penetration (greater than 500md) in low-stage areas, flood-prone, high track and low permeability (200-300md), with the material basis of the potential layer after water blocking.
Figure 1. Horizontal section trajectory of A-101H horizontal well

Figure 2. Permeability Profile of Horizontal Section of A-101H Horizontal Well

(2) Water-out features

Figure 3. Production performance of A-101H Horizontal Well
Production was put into operation in July 2002, as of August 2017, the cumulative oil production of 198580.7t, the cumulative production of water 225140.2m³, the cumulative production of liquid 423720.9t, the pre-water control of Nissan oil 2.3t, the daily water 43m³, the daily liquid 45.3t, the water content of 95%.

1) A-101H well without water oil recovery period of 430 days, no water oil production 4.13 x 10⁴t, self-injection period of up to 3524 days. At the beginning of the water content is a slow rise law, the later steps rise, the current high water production.

2) A-101H well after the water gradually rose, after the steps rose to the high water content of the well, the bottom water first through the construction position is lower, and the penetration of the upper end and with the end-like flooding, and then gradually start the middle position of the higher well section low seepage section residual oil, resulting in overall flooding, horizontal well section low seepage section is suppressed.

3) The evolution characteristics of the remaining oil

Through the A-101H well water-bearing rise law, combined with the trajectory, penetration rate is that: the current high water content is due to the horizontal well heel and toe end position is low and the well section high seepage caused by the bottom water flooding, due to contradictions in the segment, resulting in the low-seepage section in the layer segment is not fully used.

![Figure 4. Residual oil saturation profile](image.png)

3. Target well binary composite water control design

Early through micro-visual physical simulation method, the production process and water control process of horizontal well development of the bottom water reservoir were simulated, and by injecting the dual water control system into the output end of the horizontal well, the transport characteristics of the gel, foam and residual oil were observed, and the mechanism of binary compound water-control oil-raising mechanism was clarified: Gel segment plug priority into the strong out of the water section for sealing, the subsequent injection of foam segment plug has the role of selective water blocking, blocking the high-permeable area and water-containing high flood area, blocking the high-seepage channel during
the local water around the flow of the low-seepage layer remaining oil enrichment area, while the horizontal segment production fluid profile and pressure distribution has been rebalanced. According to the theory and on-site research and understanding, according to the water-out characteristics of the target horizontal well, the combination of binary composite water control water segment plug is designed, and the design of each segment plug is shown in Table 1.

### Table 1. A-101H binary water section plug usage design table

| Slug                        | Chemical Agent                                      | Amount (m³) | Objective                                      |
|-----------------------------|------------------------------------------------------|-------------|------------------------------------------------|
| Ahead protective fluid ahead protective fluid | Alkaline solution: 2% mass concentration | 20          | Cleaning the formation                         |
| Weak gel                   | Polymer solution: 0.3% mass concentration            | 30          | Protect potential oils                         |
| Weak gel                   | Polymer solution: 0.5% mass concentration; Weak cross-linking agent system | 150         | Weak lying out of the water section            |
| Strong gel                 | Polymer solution: 0.5% mass concentration; Strong cross-linking agent system | 150         | Strong blocking out of the water section       |
| Polymer solution            | Polymer solution: 0.3% mass concentration            | 30          | Transition segment plug                        |
| Foaming liquid             | Foaming liquid: 1% mass concentration                | 20          |                                                 |
| Nitrogen                   | 98% or more nitrogen gas with purity                 | 15000sm³   | Create foam                                    |
| Foaming liquid system Nitrogen | Foaming liquid: mass concentration of 1%; Polymer solution: 0.25% | 100   | Create foam                                    |
| Nitrogen                   | 98% or more nitrogen gas with purity                 | 15000sm³   |                                                 |
| Foaming liquid             | Foaming liquid: mass concentration of 1%; Polymer solution: 0.25% | 20    | Create foam, Transitional role                 |
| Polymer solution            | Polymer solution: 0.25% mass concentration            | 50          | Replace, remove residual blockers              |
| Water                      | Clean water or oil field sewage                      | 50          |                                                 |

4. **Analysis of the application effect of binary compound water control technology**

According to the A-101H well dual control water section plug dosage design, completed the injection of binary composite water blocking agent, and suffocated well for 7 days, to be injected after a full reaction of the chemical agent in the formation to open the well, maintain the water control before the water recovery strength, the average daily production of 45t/d. After the well was opened, the water content decreased significantly, from 95.1% before water control to the lowest when about 80%, a decrease of 15 percentage points, nissan oil from 2.3t/d before water control to the highest 9t/d after water control, cumulative oil increase 550t, valid for 135 days, oil precipitation effect is obvious.
5. Conclusion

(1) Based on the comprehensive analysis of interaction relationship between horizontal segment trajectory and oil and-water interface, the distribution and contrast of permeability along horizontal segment and production performance, the flooding characteristics and the location of the water out ingress of the target well are defined.

(2) The development history matching of the target well is completed by reservoir numerical simulation. The fitting result reveals residual oil distribution characteristics of the target well and verify the analysis conclusion of flooding characteristics, also provides a basis for the design of dual compound water control mode and dosage.

(3) Through the investigation of water control technology at domestic and international, the research direction of the water control system is clarified and the temperature-resistant salt-control water control system that is frozen glue and foam system for the harsh reservoir conditions of Tahe oil field is screened. The research results provide technical support for the efficient employ of residual oil at the top and between wells and the efficient development of debris rock reservoir.

(4) From the perspective of theory combines with the actual situation on the spot, a binary composite water control mode of injecting gel first and then injecting foam is proposed creatively, and the amount of the water control system of the A-101H well and the on-site construction are designed. After water control, the production data shows that the water content decreased significantly after opening the well, from 95.1% before water control to 80%, which was 15% lower. Also the oil production rate has a significant increase from 2.3t/d before water control to maximum to 9t/d after water control and cumulative oil increase is 550t with effective period of 135 days. The effect of oil and precipitation is obvious.

Acknowledgements

This work was financially supported by National Science and Technology Major Projects (2016ZX05058003, 2017ZX05009004).

References

[1] Zifei Fan, XiuJuan FU. Study for water cut variation of horizontal well after breakthrough in a reservoir with bottom water drive[J]. China Offshore Oil and Gas(Geology), 1995, 9(3): 213-220.

[2] Yuanliang Yang, Guohua Shen, Wenfang Song, et al. Nitrogen injection technique for controlling bottom water coning in heavy oil reservoir[J]. Oil & Gas Recovery Technolody, 2002, 9(3): 83-88.

[3] ZHOU Daiyu, JIANG Tongwen, FENG Jilei, BIAN Wanjiang, LIU Yong. Water flooding
performance and pattern in horizontal well with bottom water reservoir[J]. Acta Petrolei Sinica, 2004, 25(6): 73-77.

[4] Liu Jianmin. The Institute of Ocean Petroleum organized experts to discuss the new development thought for water control and stable oil in Suizhong 36-1 oilfield [J]. China Offshore Oil and Gas(Engineering), 1996, 26(3): 26-28.

[5] Hui Liu, Haitao Li, Jincheng Shan, et al. Optimization of completion design for horizontal wells in bottom water drive sandstone reservoirs [J]. Drilling & Production Technology, 2013,36(5):37-40.

[6] Jiankun Cao, Shengzhu Yang, Hongqiang Zhang, et al. A research for water shutoff in the bottom water reservoir [J]. Petroleum Exploration and Development,2002;80-81.

[7] Fengguo He, Xiangan Yue. The influence of horizontal well trajectory on recovery effectiveness of bottom water oil reservoir [J]. Journal of Southwest Petroleum University(Science & Technology Edition),2009,18(6):52-55.

[8] Shixiong Wu, Xingfu Zhong, Xingbing Liu, er al. Tech of production profile logging in horizontal well and its application[J]. Well Testing,2005(14)2:57-59

[9] Tao Wang, Xiangfang Li, Yuedong Yao, et al. Technical limits of developing positive rhythm reservoir with bottom water by horizontal wells [J]. Special Oil & Gas Reservoirs,2009,16(1):58-60.

[10] Zhu H J,Xu Z D.Luo J H,et al. Technologies of water and gas shuttoff in horizontal wells:an overview.Oilfield Chemistry.2004:21(1):102 105

[11] Dai C L,Zhao F L,Li Y L,et al.Control technology for bottom water coning in horizontal well of off'shore oilfield.Acta Petrolei Sinica,2005; 26(4):69～72

[12] WANG Jialu, LIU Yuzhang, JIANG Ruyi, GUAN Changzhi.2-D physical modeling of water coning of horizontal well production in bottom water driving reservoirs[J]. Petroleum Exploration and Development, 2007, 34(5):590-593.