Segmented Well Inflow Control with Intelligent Completions: A Comparative Study

Zhong Cheng[1,2](✉), Liang Zhang[1,2], Xiao-long Yu[1,2], Ning Li[1,2], Zhou-zheng Hao[1,2], Xiang-xiang Ding[1], Jia-xuan Gao[1,2], and Jie Cao[2]

[1] CNOOC Ener Tech-Drilling and Production Co., Tianjin, China
chengzhong@cnooc.com.cn
[2] Faculty of Petroleum Engineering, Xi'an Shiyou University, Xi'an, Shaanxi, China

Abstract. Intelligent completion, also called smart well technology, involves downhole measurements and remote well inflow control for the purposes of improved production efficiency and better reservoir management. The intelligent completions are valuable techniques, especially for offshore field developments where the workover process and treatment of water production are expensive. The inflow control devices (ICDs), for example, can be used to improve the well production performance by reducing water production and delaying water breakthrough. The undesired water breakthroughs occur due to several factors like the near-well reservoir heterogeneity, the frictional pressure gradient from the heel to the toe, and the regional differences between various perforated reservoir segments. In this paper, we present a comparative study using a network well model for optimized ICD control in different isolated reservoir segments. The network well model can model the wellbore and near-well flow accurately, and therefore predict the production profiles. It serves as the fundamental knowledge and reliable basis for the appropriate design and planning of the ICDs. For the horizontal well in the anisotropic reservoir, we proposed three completion designs with evenly and unevenly distributed perforations, and ICDs. The simulation results for the production profile are compared among the three scenarios. The results demonstrate that the proper design and application of ICDs can dramatically mitigate the undesired water produce and delay the water breakthrough. It is also shown that ICDs mainly contributes to the minimization of heel-toe effects. The successful application of ICDs requires a thorough knowledge of reservoir properties, the accurate modeling of well flow.

Keywords: Intelligent completion · Network well model · ICD · Water coning

1 Introduction

There are complex construction and strong inhomogeneity of most of our country's reservoirs, so the recovery is unideal. Most oil fields choose water injection to supply the formation energy and raise recovery ratio, so the character tends to the bottom water reservoir's. For which, the most important is to avoid bottom water breakthrough. There is a pretty solution for it, that is drilling horizontal well. While with the widespread application of horizontal well, some relevant problems have exposed.

J. Lin (Ed.): IFEDC 2020, SSGG, pp. 2178–2184, 2021.
https://doi.org/10.1007/978-981-16-0761-5_205

Effected by frictional pressure drop and inhomogeneity, its production reduces and the water breaks quickly, so there are difficulties in seeking and plugging water. Which leading that the inflow profile can't advance in a balanced position, the production ratio and benefits are effected. So the completion and water control become a technical problem in developing horizontal wells. This paper has concluded present conditions and application situation of smart completion and water control of horizontal well at home and abroad. And by controlling the inflow and frictional pressure drop, we can get the best completion in models. So we can maximize the completion intelligence to improve the production efficiency and recovery ratio.

The horizontal well has serious heel to toe effect which cause unbalanced percolation flow, and the most important problem is the coning of the bottom water and local sudden advance. Then the rate of flow decreases suddenly and rate of water increase sharply leading to water flooding, which control the production process and benefits. So the main thing of horizontal well completion and water control is to control a balanced propulsion by balancing and rebuilding the water-oil contact, which could curb the increase of water. Eventually it can prolong the period of water free conduction and water breakthrough and increase recovery ratio.

For non-homogeneous reservoir, the horizontal permeability is greater than vertical permeability, so there is resistance of the bottom water upward coning. And if there is continuous or impermeable interlayer, the coning will be delayed or interdicted. For homogeneous reservoir, we can stabilize the water-oil contact to ease the coning by controlling the oil production rate. Referring to the coning steady condition in Guodong Yu's doctorate paper, we can conclude that: whether there is a coning rise depends on the pressure difference. If the pressure difference is greater than the oil-water density difference, the coning will rise; otherwise, the coning is steady.

It is noted that the first paragraph of a section or subsection is not indented. The first paragraphs that follows a table, figure, equation etc. does not have an indent, either.

Subsequent paragraphs, however, are indented. Most of reservoir is bottom reservoir. While with the production entering the second stage, the production character tends to the bottom water reservoir. So we need technique of stabilizing oil and controlling water to enhance recovery rate.

In previous research, Crow et al. (2006) proposed clip AICD which could control oil-gas ratio depending on the opening and closing of clip by the oil and gas density difference, but it didn't work for reducing water cut. Lease et al. (2012) proposed flow channel AICD, and it could make the fluid flow out along different ways which can divide phase and decrease water cut according the viscosity difference. Zhao et al. (2014) proposed floating disc AICD that mainly decreases gas cut, and due to the gas integration the pressure on disc increases so that the flow paths are closed. Zeng proposed inflation AICD, with which the open areas limit the water inflow for internal inflation material expend with water. Foreign scholars had applied these AICDs in different fields to justify their validity, and compared these in one field. Tests showed that the water and gas cut decrease obviously so it can be used popularized. By numerical simulation and economic evaluation, the optimization methods and steps of AICD design can reduce construction risk efficiently (Youngs et al. 2009; Eltaher et al. 2014; Ghosh et al. 2013; Thornton et al. 2012).

2 The Completion Methods for Water Control

There are several completion techniques:

2.1 Normal Horizontal Well Completion and Water Control Technical

For perforated completion, we can modify the length, pore diameter, density, position and so on to change the inflow profile and balance the advance of waterline comparing the property of each layer. For normal completion, the improvement effect is not obvious for normal horizontal well, but for reservoir of high permeability contrast. For slotted liner completion, the main is to delay the time of coning and change its pattern by adjusting the slot's parameter such as size.

2.2 Dual String Completion

There are 2 flow matrices separately for oil and water layer to control their synchronously delaying failing pressure. Which reduces coning and local breakthrough, thus delays water breakthrough and avoid water flooding. Comparing with formations of different property, we conclude: for low pressure and dense formation, after adapting this technique, there is obvious effect in increasing production as much as 2.6 times. While there are difficulties in technique and tools, so we could promote it in shallow low pressure and dense reservoir. For normal reservoir and high pressure reservoir, we don't adapt it for its unobvious effect and complex process.

2.3 AICD and ICD Completions

This technique uses subsurface sensors to make it smart. It can monitoring the flow pressure and rate to control ICV's (Inflow Control Valve) open degree. And then the valves could control the flow rate, balance production and the advance of water-oil contact, which could delay water breakthrough, change waterflooding model, and avoid coning and local breakthrough as much as possible. In fact ICV is a flow control device, so it means that we could change its resistance and flow section by adjusting open degree in order to control flow rate.

ICD is divided into rotating channel, nozzle and tubular. ICD is invalid after water breakthrough so it is used before water breakthrough. And it usually used together with sand control screen which can balance pressure drop of horizontal section and production. ICD is a special completion device, so when there is flow between annular and oil tube, it can impose restriction on the flow. Actually it adjusts flow screen with undersurface devices, and sets flow rate of each ICD to adjust pressure drop and finally balance pressure drop of horizontal section, control flow rate and delay water breakthrough.But the flow rate can be changed once the ICD is set into the well, so we have to presuppose flow rate. These positions and sets are designed in NETool. And now there is AICD (Autonomous inflow control device) which is the updated version of ICD. And it can separate flow of each phase, and add a rotating pressure drop to water flow to change the water flow line. So this technique could help us control water better, balance production profile, remove heal and toe effect and annular effect so as to prolong oilfield life and enhance recovery rate mainly for medium and high water cut. This technology can achieve intelligent control of water, increase production, so there are good application prospects.

3 Case Studies with NETool™

In NETool simulation software, we stimulate the production process before and after using ICD, and record the oil, gas and water rate before and after, then compare the changes of production and water cut. That is the process is as the following. First distribute different horizontal parts depending on reservoir parameters and completion combination way in Fig. 1. After blocking, design partial packing and water control of completion: click reservoir model 'Sweet Spot', then the case 'Bitter well start' and run it. There is a inflow curve and study it. I can ensure the segments of each output and get the high water and gas cut area.

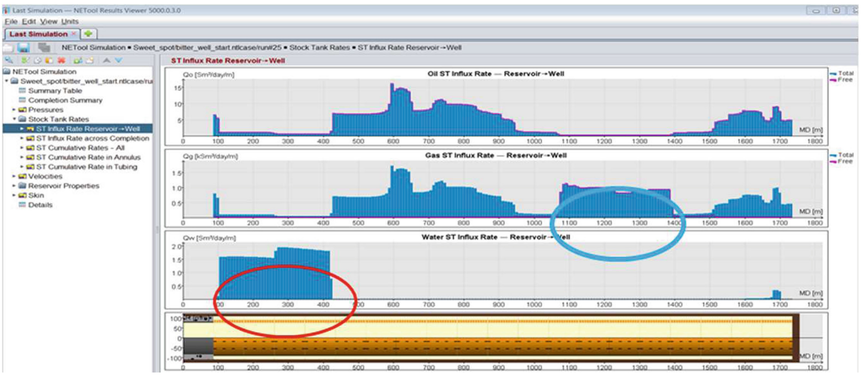

Fig. 1. Horizontal well's flow distribution chart of 3 phases

From the picture, the oil production part is concentrated in 2 segments: 400 m–950 m, 1500 m–1750 m. The gas production part concentrated in 3 segments: 400 m–950 m, 1050 m–1400 m, 1500 m–1750 m and the water production part in just 1 part: 100 m–410 m. I pack off the high gas cut segment in blue circle and high water cut segment in orange circle, then study the changes before and after isolation. Change the completion from slotted liner to the combination: ICV + packer + blank pipe, detailed steps:

(1) Adjust completion way of 2–6, 13–21 segments;
(2) Set the packer and ICV length of 3, 6, 13, 18 and 20 segments to 1 m.

That is the new completion way as follow (Fig. 2):

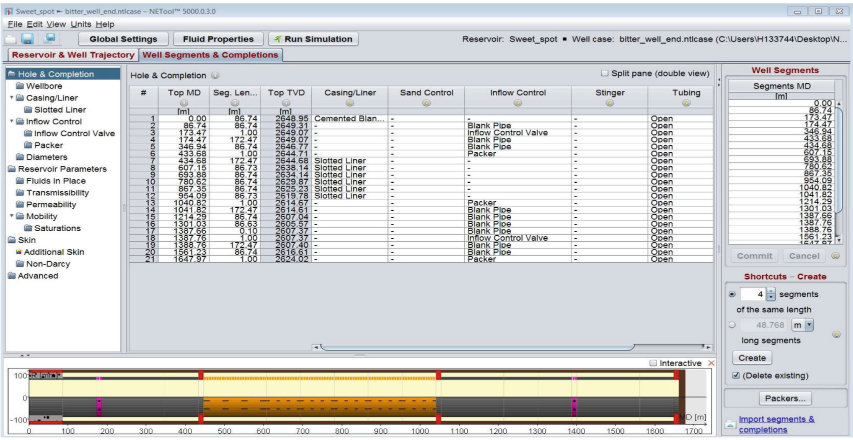

Fig. 2. Modified completion set

Choose ICV in Hole and Completion and change Pressure Drop calc. to Nozzle diameter. Then set #3 diameter to 3 mm, #18 diameter to 15 mm (Fig. 3).

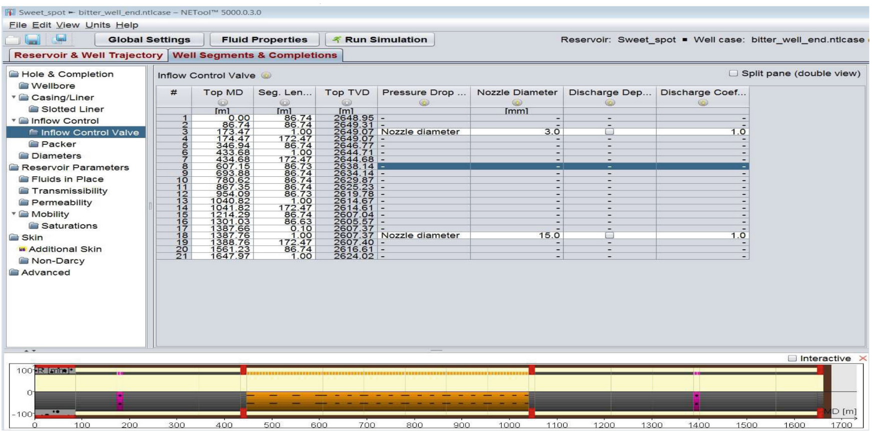

Fig. 3. ICV settings

Output the changing flow rate chart, as shown in Fig. 4.

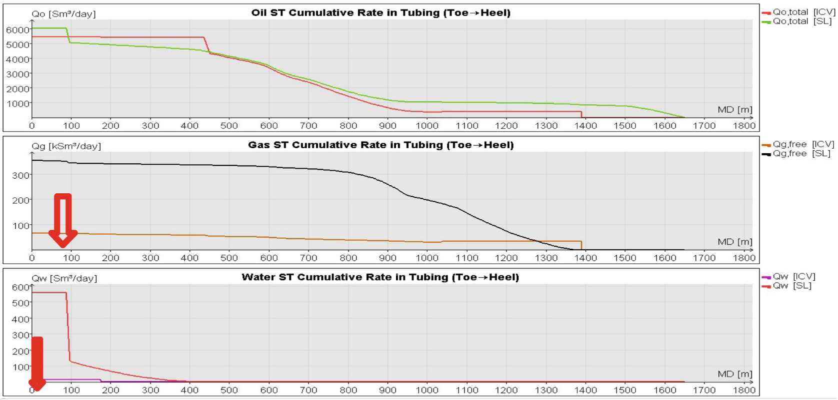

Fig. 4. Flow rate comparison chart

Comparing the changes of flow and recovery ratio, we can conclude that the gas and water production rate decrease by 36% and 97%. And eventually the water ratio goes down to 0.29% that is a condition with a little water. Though the oil production decreases by 10%, the goal balancing oil and controlling water has achieved. Therefore, ICD becomes an important method for controlling water in the later period of production for this example (Table 1).

Table 1. Flow rate comparison chart.

UNIT	Oil rate (Sm^3/d)	Gas rate ($MMSm^3/d$)	Water rate (Sm^3/d)	GOR (Sm^3/Sm^3)	WCUT (%)
Slotted liner	6031	0.97	558	161	8.5
ICV	5443	0.62	16	114	0.29
Decrease, %	10	36	97	29	97

4 Conclusions

In this paper, we discussed the problems associated with water conning and its completion methods. We use the NETool software to stimulate the production process before and after using ICD, and record the oil, gas and water rate before and after, then compare the changes of production and water cut. By distributing different horizontal parts depending on reservoir parameters and completion combinations, the recovery results demonstrate that proper arrangement of well segmentation and control of ICD settings can decrease the water cut. More simulation and optimization work can be further carried on for a better control.

Acknowledgments. The authors thank the Natural Science Foundation of Shaanxi Province (No. 2019JQ-525) and the Open Fund (PLC2020036 and PLC2020055) of State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation (Chengdu University of Technology) for the support without which this work could not have been performed.

References

Soleimani, R., Jahanpeyma, Y., Salehian, M.: Analysis of horizontal well productivity in tight gas formations and its sensitivity to reservoir properties. J. Pet. Explor. Prod. Technol. **9**(2), 1237–1244 (2019)

Armenta, M., Wojtanowicz, A.K.: Incremental recovery using dual-completed wells in gas reservoirs with bottom water drive: a feasibility study. J. Can. Pet. Technol. **44**(06) (2005)

Etesami, D., Ahsan, S.: The optimization of a slotted liner design for a horizontal well. Pet. Sci. Technol. **31**(21), 2178–2190 (2013)

Birchenko, V.M., Muradov, K.M., Davies, D.R.: Reduction of the horizontal well's heel–toe effect with inflow control devices. J. Pet. Sci. Eng. **75**(1–2), 244–250 (2010)

Naus, M.M.J.J., Dolle, N., Jansen, J.D.: Optimization of commingled production using infinitely variable inflow control valves. Spe Prod. Oper. **21**(2), 293–301 (2006)

Mibang, W.: Application and enlightenment of foreign AICD technology. Sino-Glob. Energy **21** (04), 40–44 (2016)

Sun, X., Bai, B.: Research status of horizontal well water control technology at home and abroad. Pet. Explor. Dev. **44**(06), 967–973 (2017)

Wang, L., Feng, Y., Yuan, P., Li, Y., Bi, J.: Intelligent well completion AICD technology and its application in China. J. Qilu Univ. Technol. **33**(06), 34–39 (2009)