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Optimization of AICD water control completion technology for horizontal well in bottom water gas reservoir

Guohui Zhang[1], Liangchuan Li [1], Rongchen[1], Pengwang[1],Guowen Zhang[1], and Jiewen Sun[1]

[1]PetroChina Research Institute of Petroleum Exploration & Development, Beijing 100083, China

Abstract. At present, adaptive inflow control (AICD) water-controlled completion technology is mainly applied to reservoir water control. In view of the gas reservoir AICD water control completion technology research is still blank, this paper carried out a suitable for gas reservoir water control water control mechanism of the new type runner AICD and flow characteristics analysis, X oilfield bottom water reservoir is established new port type AICD water control completion. The structure parameter combination of the new AICD was analyzed and optimized by orthogonal test, and the water control effect of the new AICD water control completion was analyzed. The results show that compared with conventional perforation completions, the new AICD controlled water completions cause little bottom hole pressure loss and have little effect on condensate production. New type runner AICD completion can prolong the bottom water reservoir water control in low yielding water gas recovery period of about 365 days, predict 20 years of accumulated water rate reduced about 27%, water saturation near wellbore area is generally lower, has good effect of water control. The new flow channel type AICD controlled water completion can be applied to the development of bottom water gas reservoirs to control water and stabilize gas.

1 Introduction

Horizontal wells have been widely used in oil and gas field development. Compared with vertical wells, horizontal wells can achieve greater reservoir contact area and lower pressure drop. In homogeneous reservoirs, the "toe effect" in horizontal well production leads to uneven flow profile distribution along the wellbore. However, in heterogeneous reservoirs, the flow profile of horizontal wells is greatly affected by reservoir heterogeneity, and early water intrusion occurs at the heel of the well or in the high permeability area, thus reducing the recovery factor [1-2].

For bottom water gas reservoirs developed by horizontal Wells, reasonable and effective water control completion technology is the key to efficient development of bottom water gas reservoirs [3]. The water control effect of conventional water control completion technology is limited and it cannot effectively solve the water control problem of bottom water gas reservoir. Adaptive inflow control device (AICD) is a new type of completion technology. At present, the AICD that has achieved commercial application mainly includes flow channel type and floating disc type [4]. It has achieved good water control effect in bottom water reservoir application [5-6], and is a completion technology worthy of research and promotion in bottom water and gas reservoir. However, at present, AICD water-controlled completion technology is mainly applied to reservoir water control, and the research on AICD water-controlled completion technology for gas reservoirs [7-8] is still not perfect. In the early stage of bottom water condensate gas reservoir in X oilfield, water invasion was very prominent, which seriously affected the normal production of gas wells [9-12].

In this paper, the bottom water condensate gas reservoir of X oilfield was taken as the research target, and the dynamic simulation study of the new AICD water controlled completion technology in bottom water gas reservoir was carried out, and the parameters of the new AICD water controlled completion were optimized.

2 Adaptive inflow control device

2.1 Adaptive inflow control device

Adaptive Inflow Control (AICD) is the core component of AICD water-controlled completion technology. This paper studies a new type of flow channel AICD. Its basic structure is shown in Figure 1, which mainly includes inlet channel, main channel, branch channel, spiral channel and outlet nozzle. The new channel type AICD has the function of automatic phase selection, and controls the flow mode of fluid by using the difference of viscous force and inertia force between different fluids [4], so as to achieve the purpose of stabilizing oil and water or stabilizing air and water. Specifically, when oil and water flow into the new AICD channel, the flow of oil is mainly controlled by the viscous force, so the oil is more easily diverted into the branch channel and flows

* Corresponding author: zhangguohui@petrochina.com.cn

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to the outlet nozzle along a shorter path, with a smaller flow pressure drop. On the contrary, the flow of water is mainly controlled by the inertial force, so the water is not easy to turn, but along the main channel high-speed flow, flow to the outlet nozzle after several turns of rotation, flow pressure drop is large. When gas and water flow into the new AICD flow channel, the phase state and fluidity of gas are very different from that of water. The flow resistance of gas is very small, and it is easy to flow to the outlet nozzle, and the flow pressure drop is small.

2.2 Flow characteristics of the new channel type AICD

Physical simulation experiments were carried out to evaluate the flow characteristics of the new channel type AICD, and the experimental pressure drop curve of oil and water flowing through the new channel type AICD with an outlet nozzle diameter of 3 mm was obtained. In addition, according to the results of the latest gas-water physical simulation experiments, the flow pressure drop of the airflow through the new channel AICD is very small, and the water pressure drop ratio can reach hundreds of times under the same volume flow. According to the comprehensive analysis, the new channel type AICD has the greatest flow limiting effect on water, the least on oil, and the least on gas.

3 Dynamic simulation of a new type of AICD controlled water completion

3.1. Dynamic simulation strategy

In order to study the applicability and water control effect of the new AICD water controlled completion technology in bottom water gas reservoirs, Eclipse software was used to carry out the design and dynamic prediction of the new AICD water controlled completion technology. According to the fluid phase characteristics of bottom water condensate gas reservoir and horizontal well development mode in Tahe oilfield, component model and multi-stage well model are used in dynamic simulation.

3.1.1 Compositional model

There is reverse condensate phenomenon during the development of condensate gas reservoir, which makes the composition of formation and wellbore fluid constantly change with the change of temperature and pressure. Therefore, it is necessary to consider the phase characteristics and variation rules of the fluid, and apply the phase equilibrium theory to calculate the composition and physical property parameters of the mixed fluid when studying the water control technology of condensate gas reservoir.

At present, PR (Peng-Robinson) equation is widely used in phase state calculation of hydrocarbon system, and the prediction results are highly reliable..

3.1.2 Multi-stage well model

The multi-section well model can divide the horizontal well to be simulated into multiple well sections, and each well section is connected to one or more grids, which can more accurately simulate the well trajectory. The multi-section well model takes into account the frictional pressure drop in the wellbore and can reasonably reflect the "toe effect" in the horizontal wellbore. In each stage of the multi-stage well model, by solving the mass conservation equation of oil, gas and water and the flow pressure drop equation, the flow rate and flow pressure drop of oil, gas and water in each stage are obtained.

3.2 Dynamic model establishment

Aiming at bottom water condensate gas reservoir of X oilfield, a new flow channel type AICD water controlled completion dynamic simulation study was carried out. The bottom water condensate gas reservoir in Tahe Oilfield is a condensate gas reservoir with bottom water and no oil circle under normal temperature and atmospheric pressure. The reservoir reserves are small, and it is exploited by depletion mode. The exploitation horizon is in Cretaceous Shushanhe Formation, which can be divided into three layer groups from top to bottom: K1 gas layer, sand and mud interbed and K_3 gas layer. The reservoir, fluid and wellbore parameters of the bottom water condensate gas reservoir are shown in Table 1.

Table 1. basic parameter X oilfield bottom water condensate gas reservoir modeling

parameter	value	parameter	value
Gas reservoir central depth /m	3950	Pressure /MPa at the middle depth of the gas reservoir	43.21
Dew point pressure /MPa	43.02	Temperature /℃ at the central depth of the gas reservoir	94.8
Rock compression coefficient /10^{-4} MPa^{-1}	0.25	Density of condensate(/ kg/m^3)	768.2
Relative density of natural gas	0.77	Density of formation water (/ kg/m^3)	1153
Horizontal wellbore diameter /mm	215.9	New AICD water controlled completion length /m	159
New flow channel type AICD water control screen tube diameter /mm	180	New flow channel type AICD water control screen inner diameter /mm	121.4
Height to avoid water /m	6.3	Gas deviation coefficient	1.04

Based on the logging interpretation results and small layer correlation data of bottom water condensate gas reservoir in X oilfield, a geological model of gas reservoir was established with a modeling area of 35.0 km^2 on the basis of the study on the characteristics of gas reservoir and reservoir heterogeneity.

Well Q2 is a horizontal well with the application of new flow channel AICD controlled water completion in the bottom water condensate gas reservoir of X Oilfield. Based on the overall geological model of the gas reservoir, a single well geological model of Q2 is established, with an area of 1.9 km2, a plane grid step of 10m×10m, and a total of 12 grids are divided vertically. According to the phase state experiment results of well Q2, the experimental data (dew point pressure, relative volume, deviation coefficient and condensate volume) were fitted by using three-parameter PR equation of state, and the pressure-temperature phase diagram of the fluid was obtained.

According to the interpretation results of well Q2's permeability logging, and considering the well diameter and reservoir interpretation conclusions, a new type of flow channel AICD controlled water completion design was carried out. Based on the design results, the Q2 well was equipped with a 3-stage oil swell packer and 13 new AICD water control screens.

In the low permeability section, the water control screen with low strength coefficient is selected. In the high permeability section, a high strength water control screen is used. The Q2 single well geological model was loaded into the Eclipse software. Considering the phase characteristics of formation fluid, the multi-stage well model was used to construct a new flow channel type AICD water controlled completion wellbore. Finally, the coupled reservoir and wellbore dynamic model of well Q2 was established. According to the rational production analysis of single well and the production situation of adjacent wells, the designed gas production of well Q2 is 3×10^4 m^3/d.

4 Analysis on the effect of the new AICD water controlled completion

4.1. Optimization of new AICD structure parameters

The dynamic prediction of well Q2 compared two completion methods: conventional perforation completion and the new AICD controlled water completion. In the design of the new AICD water control completion, different structural parameter combinations of the new AICD have great differences in water control effect. Therefore, it is necessary to optimize the structural parameters of the new AICD according to formation and wellbore conditions. The key parameter combinations for parameter optimization are the strength coefficient, flow index and viscosity index of the new AICD flow channel. Referred to the pressure drop curve of the AICD experiment of the new flow channel, different parameter combinations were set in the dynamic model, and the orthogonal test method was used to design the three-level and three-factor orthogonal test (Table 2).

Table 2. Structural parameters of the new channel-type AICD for orthogonal test

Test number	Intensity coefficient of new type AICD in low permeability section	Flow index	Viscosity index
1	0.001	1.0	0.1
2	0.001	1.2	0.2
3	0.001	1.5	0.5
4	0.002	1.0	0.2
5	0.002	1.2	0.5
6	0.002	1.5	0.1
7	0.003	1.0	0.5
8	0.004	1.2	0.1
9	0.004	1.5	0.2

Orthogonal tests were used to predict the performance of 9 new AICD controlled water completions (Table 2). Compared with conventional perforation completions, orthogonal test results were obtained (Table 3). The strength coefficient of the new type AICD in the high permeability section is 2 times that of the new type AICD in the low permeability section. Since the initial water production of conventional perforation completions is up to $2.3m^3/d$, the low-water production gas production period of the new AICD controlled water completion is defined as the production with water production less than $2.3m^3/d$

Table 3. new port type AICD water control completion the orthogonal experiment results

Test number	Low water production gas production period /d	The cumulative water rate change / %
1	305	-28
2	245	-24
3	/	/
4	0	-4
5	110	-2
6	365	-27
7	30	82
8	25	23
9	20	121

4.2. Analysis of water control effect

The optimal structural parameter combination of the new type of AICD was used to predict the performance of the new type of AICD controlled water completion in well Q2. The bottomhole flow pressure, daily oil production, daily water production and cumulative water production were obtained and compared with the corresponding parameters of the conventional perforation completion. Compared with conventional perforation completions, the bottom hole pressure and condensate production of the new type of AICD controlled water completion are very small, indicating that the pressure drop of the fluid flowing through the new type of AICD controlled water screen is small, and no significant pressure loss is caused. At the same time, the installation of the new AICD water control screen has little effect on the condensate production, and no condensate loss is caused.

Compared with conventional perforation completions, the new AICD controlled water completion produced less water per day and cumulative water production. The new AICD water-controlled completion can prolong the low-water-producing gas production period by about 365 days, and it is predicted that the cumulative water production in 20 years can be reduced by about 27%, showing good water control effect.

5 conclusion

The new AICD has obvious flow limiting effect on water, but little effect on gas. The new AICD water control completion technology can be applied to bottom water gas reservoirs to realize the purpose of water control and gas stabilization.

When applying the new AICD controlled water completion technology in bottom water condensate gas reservoirs, it is necessary to consider the fluid phase change law and reverse condensate characteristics to prevent the condensate blockage and loss caused by too much reduction of bottom hole pressure.

The orthogonal test method was used to optimize the structural parameter combination of the new AICD, which effectively enhanced the water control effect of the new AICD water control completion.

4.4. Compared with conventional perforation completions, the new AICD water-controlled completion has little effect on bottomhole pressure and condensate production. It can prolong the low-water-producing gas production period by about 365 days, reduce cumulative water production by about 27%, and generally reduce water saturation in the near-wellbore zone.

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