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Practice of improving development effect in ultra-high water cut stage of multilayer sandstone reservoir

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Abstract
Offshore oil fields face many problems after entered the ultra-high water cut stage, including low efficiency of production wells caused by serious water channeling and poor effect of conventional injection production structure adjustment. In order to solve these problems, differential optimization injection production research based on the main contradiction between layers was carried out. The research method is mainly based on the analysis of injection production relationship and the results of production test data, so as to accurately determine the location of remaining oil and make targeted adjustments. The research results show that for the oil formation with good physical properties and historical long-term dominant water channeling channels, the weak effective direction should be adopted to improve the liquid production of production wells and combination with the horizontal profile control technology of injection wells; For the formations with poor physical properties and poor injection production relationship, acidizing of injection wells should be adopted to supplement reservoir energy, and fine water injection should be realized in combination with subdivision of water injection sections; According to the analysis of oil-water redistribution, the remaining oil can be effectively used by re perforation the moderately swept layer that avoids perforation at the initial stage of production, and combination with the closure of the seriously swept layer of the injection well. The research results guide the production and injection wells measures in the field for 13 wells, and the average oil production of a single well is increased by 1.3 times, effectively improving the development effect of the oilfield in the ultra-high water cut period.

Keywords: *Ultra-high water cut stage, Multilayer sandstone reservoir, Measure combination, Field practice, Offshore oilfield.*

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I. INTRODUCTION

Water flooding is one of the most common development methods of offshore multi-layer sandstone reservoirs. Through water flooding development, it can maintain enough energy and relatively stable production in the initial stage of oilfield development [1-5]. However, with the extension of development time and the deepening of development stage, the development contradiction has gradually become prominent after the large-scale water breakthrough of production wells in the oilfield. The main problem is that the water cut rises rapidly, the production decline increases, and the oilfield will quickly enter the high water cut stage or even the ultra-high water cut stage [6-7].

The contradiction between layers can be alleviated to a certain extent by profile control and water plugging [8-9]. However, it is difficult to effectively change the trend that the overall water cut of the oilfield increases faster. Some studies have pointed out that the development of layered system can effectively alleviate the interlayer contradiction in the process of water drive. However, in the stage of ultra-high water cut, oil production wells generally enter the stage of high fluid production. Offshore oil fields are limited by the size and working space of high displacement electric pumps, and generally can only be put into the commingled production string for multi-layer commingled production [10]. The switch layer needs to cooperate with the movable string operation. Considering the tight construction period and high operation cost of offshore platform operation, it is difficult to realize the development of layered system in the oilfield.

Based on the experimental research results of high multiple displacement, after entering the ultra-high water cut stage, the oilfield still has great potential reserves that can be exploited [11-12]. Therefore, based on the existing development well pattern, development mode and development conditions, it is necessary to summarize a set of methods to improve the development effect of multi-layer sandstone reservoirs in the ultra-high water cut stage.

II. MAIN PROBLEMS IN ULTRA-HIGH WATER CUT STAGE

The main production layer of offshore oilfield A is the I, Ⅱ, Ⅲ and V oil formations in the Lower East second member of Dongying Formation, which is a typical multi-layer sandstone reservoir. At present, the comprehensive water cut has reached 92%, entering the ultra-high water cut stage. The average daily oil production of a single well is only about 13m^3. The economic benefits of the oilfield are facing great challenges. According to the research and analysis of the overall production and testing data of the oilfield, the following three problems are mainly faced of offshore oilfield A in the ultra-high water cut stage.

2.1 Uneven Horizontal Water Flooding

The overall reservoir of oilfield A is well connected between injection and production wells. According to the tracer monitoring results, the agent can be seen in the production wells in all directions in the same injection and production well group, but due to the heterogeneity of the reservoir plane, the advancing speed of the agent front and the agent concentration are quite different in different directions. On the other hand, the liquid production capacity and residual oil saturation of single wells on the plane are quite different. For the injection and production wells of the initial well pattern, the cumulative injection volume is high, and the sweep degree of injected water is high. As for the newly infilled adjustment well, it is in a weak water flooding direction after being put into production and is poorly swept by the injected water.

2.2 Serious Contradictions between Layers

At the initial stage of oilfield development, the vertical water injection profile is relatively uniform. With the development, the interlayer difference gradually increased. After many acidizing modifications and profile control, it has been relieved in a short time. At present, layered injection is used in injection wells to reduce interlayer interference, but interlayer contradictions are still prominent. The start-up pressure of each water injection section in the same sand control section varies greatly, and the start-up pressure of water absorption in different layers is between 10MPa and 12MPa. At the same time, there are obvious differences in the production of each layer in the same sand control section, and there are great differences in the decline of oil saturation in different layers.

2.3 High Water Cut Caused by Strong Flooding

At present, the oil field production wells generally enter the stage of high water cut, and the average liquid production of a single well is 260m^3/d, of which 52% of the wells have water cut higher than 95%. Inefficient wells are all caused by high water cut. In the extremely high water cut period, these wells still maintain a high water cut rise rate. In 2021, the water cut of the oilfield increased from 91.7% at the beginning of the year to 94.6% at the end of the year, an increase of 2.9 percentage points. Among the 24 production wells, the water cut increased by about 3 percentage points, accounting for 47%.

III. RESEARCH ON GOVERNANCE METHODS

The main production layer of offshore oilfield A is the I, Ⅱ, Ⅲ and V oil formations in the Lower East second member of Dongying Formation, which is a typical multi-layer sandstone reservoir. At present, the comprehensive water cut has reached 92%, entering the ultra-high water cut stage. The average daily oil production of a single well is only about 13m^3. The economic benefits of the oilfield are facing great challenges. According to the research and analysis of the overall production and testing data of the oilfield, the following three problems are mainly faced of offshore oilfield A in the ultra-high water cut stage.

3.1 Replace the Pump to Improve the Fluid Production Combination with the Plane Profile Control

Oilfield A adopts the row injection production well pattern, and adjusts the potential tapping area to be dominated by the cross well residual oil enrichment area. From 2015 to 2019, nearly 20 production wells were infilled in the above areas. These infill production wells and old wells produce oil formations Ⅰ, Ⅱ, Ⅲ and V at the same time. Affected by the long-term water injection and production channeling channel between old wells, the injected water is difficult to effectively spread to infill production wells. The poor development effect of infill wells is mainly affected by the planarity difference and low energy level. Take production well A20 as an example, the corresponding injection well is A2-2 (Figure 1). Well A20 was put into operation in 2019, located at the edge of the well area, with an effective thickness of 33.6m. Its sedimentary microfacies are mainly underwater distributary channels. The reservoir physical properties of formations Ⅰ and Ⅱ are good, while those of oil formations III and V are poor. At present, the daily liquid production of well A20 is about 300m^3. According to its liquid production profile (Figure 2a), the main liquid production and oil production layer are oil formation Ⅰ, and the liquid production accounts for 84% of the whole well. On the other side of A2-2 well, the oil production wells A2-3 and A1-2, which were put into operation in 1999, were extracted by replacing large pumps and fracturing measures. The liquid production profile of well A1-2 (Figure 2b) shows that its oil formations Ⅱ and Ⅲ have strong production capacity, while the water absorption profile of well A2-2 shows that oil formations Ⅰ, Ⅱ and Ⅲ have good water absorption capacity. It is analyzed that the long-term injection production correspondence makes A2-3 and A1-2 become the dominant direction of water flooding in A2-2, which makes A20 water flooding less effective. Therefore, it is proposed that well A20 fracturing oil formation Ⅱ first. Since the reservoir pressure coefficient of well A20 is 0.85 and the energy is sufficient, the large pump should be replaced after fracturing to improve the liquid production. At the same time, combination with the profile control of oil formations Ⅰ, Ⅱ and Ⅲ of injection well A2-2, and the profile control strategy is mainly plane control.

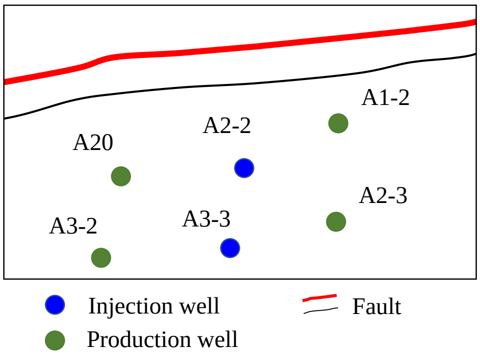
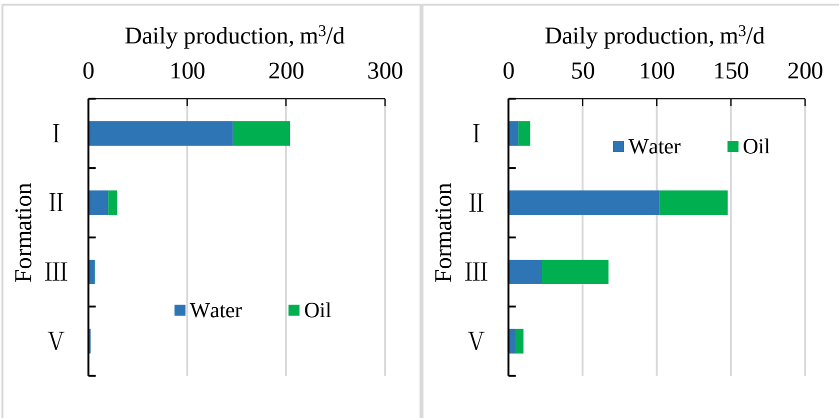


Figure 1: Relative position relationship between well A20 and surrounding injection wells



a. Liquid production profile of well A20 b. Liquid production profile of well A1-2

Figure 2: Test results of liquid production profile of production wells on both sides of injection well

3.2 Acidizing of Injection Well Combination With Subdivision of Injection Section

Oilfield A is a layered edge water reservoir. The volume multiple of water body is about 5 times, which belongs to medium energy water body. The production wells at the edge of the injection production well pattern are affected by both injection water and edge water. With the development, the edge water energy is continuously consumed, and the artificial water injection is relatively stable, so the production wells at the edge of the well pattern show the characteristics of energy decline. Take the production well A19 as an example. The well is located at the edge of the injection production well pattern of the reservoir (Figure 3), and the plane position is at the bottom of the structure. The sedimentary microfacies of well A19 are mainly underwater distributary channels and estuarine bars. The reservoir physical properties of oil formations Ⅰ, Ⅱ and Ⅲ are good. In the early stage of production in 2015, the daily liquid production was 130m^3/d. Since 2018, the liquid production of well A19 has continued to decline. At present, the production is inefficient, and the daily liquid production is only 56m^3/d. First, analyze the reasons for the decline of fluid production from wellbore factors. Well A19 is lifted by electric pump. According to the working condition data of the pump, the pressure difference at the inlet and outlet of the electric submersible pump is stable, and the power and current of the electric submersible pump decrease with the decrease of liquid production, which is consistent with the theory. Therefore, the decrease in liquid production caused by the failure of the electric pump and the leakage of the string is eliminated.

The underground potential is further analyzed through the test data. According to the production profile and the switch layer test, it is confirmed that the oil formations Ⅰ, Ⅱ and Ⅲ of the well have good liquid production capacity. According to the water injection profile data of surrounding water injection wells, the interlayer contradiction of corresponding injection well A17 has intensified after long-term water injection. The water absorption capacity of oil group I is the strongest, followed by formation Ⅱ, and formation Ⅲ is the worst, with daily water injection of only $4m^3/d$. The other corresponding water injection well A4-6 also has serious interlayer interference. Formation Ⅰ is the main water absorption layer, and the water absorption of formation Ⅱ and Ⅲ is poor. Moreover, formation Ⅰ and Ⅱ are in the same sand control section, so it is difficult to realize layered water injection. Therefore, the treatment direction is A17 layered acidification of oil formation Ⅱ and Ⅲ of water injection well. The first injection interval of injection well A4-6 is adjusted to two intervals, injecting formations Ⅰ and Ⅱ respectively, and increasing the water injection volume after acidification of formation Ⅲ.

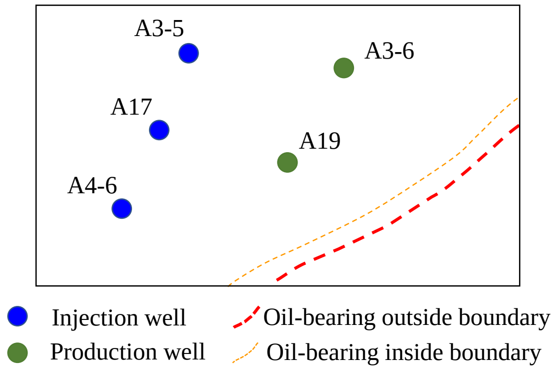


Figure 3: Relative position relationship between well A19 and surrounding injection wells

3.3 Close the High Aquifer and Increase Perforation to Tap Potential

In order to reduce the interference of high aquifer to the newly infilled production wells and ensure the maximization of initial production capacity, corresponding measures have been taken in the adjustment and infilling process of oilfield A, According to the recognition of water flooding after drilling and the calculation of oil displacement efficiency, the initial development strategy of not perforating the strong water flooded layer is determined, and obvious water control effect is achieved. After infill well production, the initial average water cut is 20% to 60%, which is lower than the average water cut of 88% of the surrounding old wells. Although the liquid production of some infill wells is relatively stable after they are put into operation, with the development process, the overall water flooding trend of infill wells is gradually enhanced, which is close to the water cut of old wells.

Take well A9 as an example, its development horizon is oil formation Ⅰ, Ⅱ and Ⅲ. according to the water flooded condition after drilling, the 4.5m strong water flooded layer at the lower part of oil formation Ⅱ of the well is not perforated (Figure 4). The overall injection production correspondence between well A9 and the surrounding injection wells is good, among which the injection production connection of oil formation Ⅰ is the best, but many layers of oil formation Ⅱ and Ⅲ of correspond injection wells do not absorb water. According to the latest profile test data, the formation Ⅰ and Ⅱ of well A9 are the main liquid producing and water producing layers, the water cut of formation Ⅰ and Ⅱ are 99.1% and 95.9% respectively, and formation Ⅲ is a low producing layer with low water cut at the same time. It can be seen that the interlayer interference of well A9 is serious, and the formation Ⅰ is explosively flooded. This layer can be closed to reduce the interlayer interference. The imperforated section in the lower part of formation Ⅱ has a good corresponding relationship with the surrounding injection wells and production wells. The long-term injection without production in the lower part of oil formation Ⅱ of well A9 is conducive to the re enrichment of oil. Referring to the old production well A5-4 adjacent to well A9, the water cut of the whole well decreased from 86.2% to 74.3% after the closure of oil formation Ⅱ in 2008. At present, the water cut of well A5-4 has reached 96.7%, so it is judged that there is still a certain residual oil potential in oil formation Ⅱ in this well area. To sum up, perforation can be added to well A9 and the remaining oil of oil formation Ⅱ can be developed.

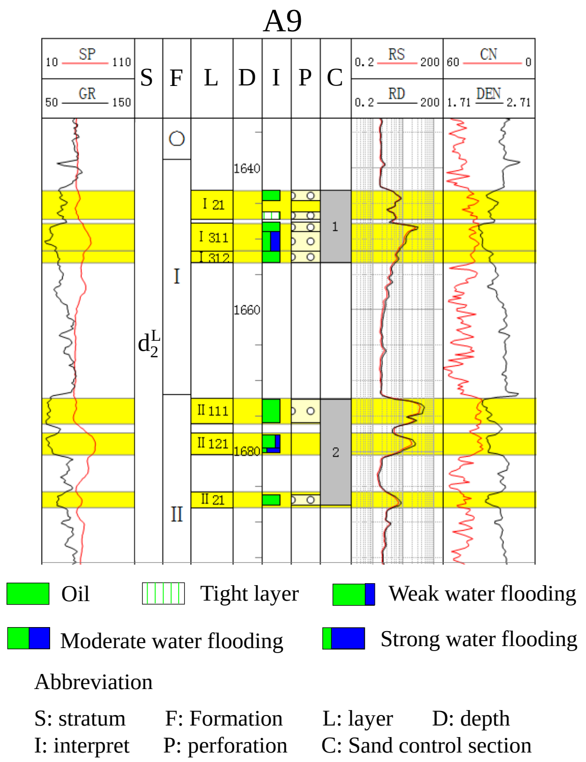


Figure 4: Perforation of production well A9

IV. OILFIELD PRACTICE OF TREATMENT MEASURES

According to the above research on treatment measures, oilfield A has carried out gradual treatment of ultra-high water cut production wells. In view of the poor effect of water flooding in infill production wells, four well fracturing measures were carried out, and according to the energy level of the reservoir, these wells were replaced with large pumps to improve the liquid production. On the other hand, the injection wells in the same well area have been carried out low-intensity and multiple rounds of profile control, so as to gradually block the dominant water flooding direction between old wells. While expanding the plane swept volume, the injected water is displaced in the original weak direction, playing the role of adjusting the plane. The average daily liquid production of four production wells such as A20 increased by $120m^3$, the water cut decreased slightly, and the average daily oil production of a single well increased by 1.3 times.

For the area where the formation energy decreases, the injection wells have been acidified for 5 wells and fractured for 2 wells, and the overall water absorption in the well area has been significantly improved. 1 injection well was subdivided into sand control sections to achieve effective water injection and fine water injection. The energy of production wells A18 and A19 was supplemented. Without replacing the electric pump, the liquid production gradually returned to the initial level, and the average daily oil production of a single well increased by 1.2 times.

According to the analysis of remaining oil and water flooding, combined with operation resources and cost optimization. Perforation was added to the lower part of oil formation Ⅱ of well A9, and the main water producing layer of oil formation Ⅰ was closed at the same time. After the adjustment of the development formation of the well, the water cut was reduced by 7 percentage points, and the daily oil increase of a single well was 1.3 times.

V. CONCLUSION

According to the main contradiction in the development of hea oilfield, the main reasons for the poor production effect of oil production wells in the ultra-high water cut stage are analyzed, including the imbalance of plane displacement, the prominent contradiction between layers, and the high water cut caused by strong water flooding.

A series of measures have been taken to solve the existing problems, including replace the pump to improve the fluid production combination with the plane profile control, Acidizing of injection well combination with subdivision of injection section, Close the high aquifer and increase perforation to tap potential. Through the cooperation of measures, it can play an effective and synergistic role.

The research results are applied to the field practice, guiding 13 production and injection well measures, achieving an average daily oil increase of 1.3 times for 7 production wells, making oilfield A production situation better, which has a certain reference significance for the oilfield management of the same ultra-high water cut stage.

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