Determination of well adjustment methods after strata reorganization of block A

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Abstract. There are four layers of well networks in Block A, and each well pattern intersects with each other without independence. By July 1997, the water content in the block had reached 90.1%, and it had entered a special high water cut period. In order to solve the problems of long perforation interval length in the block, stratification of mining strata, complicated injection and mining relationships, and outstanding contradictions between the floors. Blocks are reorganized in 2013, and after the layer adjustment, the well length is shortened, each layer is mined independently; the number of injection and production wells is smaller after well pattern and well spacing adjustment, the direction of movement of oil and water is changed; the new injection and production wells are fine reservoirs descriptions. The description of remaining oil distribution adds new insights. Therefore, the determination of the boundary of water recharge parameters after reconstitution of block layers, the division of reasonable water injection intervals, and the adjustment direction of the interval segments are important means for improving the tracking adjustment effect and enhancing the recovery ratio after the reorganization of blocks.

1. Dynamic and static features of Block A

1.1. The main geological features

Block A is located in the east of an anticline in the north of Changyuan. The dip angle of the strata is about 2° to 30°, the average ground elevation is about 147.9-153.8m. The structure is relatively gentle, gradually decreasing from southwest to northeast whose total drop is 69m.

A total of three oil reservoirs in Sa, Pu, and Gao, eight oil reservoirs, 33 sandstones, and 110 sedimentation units have been developed. The depositional environment is a large-scale river-delta deposit in the northern Songliao Basin in the middle of the Early Cretaceous. It belongs to the clastic reservoir, and the lithology of the inner surface is dominated by fine and siltstones. The average air permeability is $365 \times 10^{-3} \mu m^2$, average porosity is 26.8%, average original oil saturation is 63.1%; The outer layer of sandstone has fine grains, high shale content, poor sorting of sand and mud, poor pore permeability and low oil saturation. The lithology is dominated by argillaceous siltstone whose silt content is 66.9% and muddy content is 22.8%. The average air permeability is $23 \times 10^{-3} \mu m^2$, the average porosity is 24.0%, and the average original oil saturation is 40.8%.

With a unified pressure system, edge water and bottom water are inactive. The original formation pressure was 11.63 MPa, the saturation pressure was 10.52 MPa, and the original difference between reservoir pressure and saturation pressure was 1.11 MPa. The reservoir temperature is 43°C and the
geothermal gradient is 42°C/Km. The specific gravity of crude oil is 0.856 as well as the average crude oil viscosity is 9.2 mPa·s.

1.2. Stratigraphic Reorganization Well Pattern Evolution and Dynamic Development

There are four layers of the layered wellbore before the reorganization of the block A strata: the mining of the basic well pattern of the Saertu main reservoir using the water injection method, the use of an anti-nine-point water injection method to exploit the high, medium, and low permeability layers one-time infill well pattern of the Sa and Pu; Using the anti-nine-point water injection method to extract secondary infill wells pattern of Sa, Pu and Grade 1 reservoirs, and adopting an anti-nine-point water injection method to exploit the secondary infill well network of the low-permeability layer below Grade 2 and below. After the stratigraphic reorganization, the Saertu oil layer was adjusted to two layers: the first set is Saertu main oil reservoir foundation well pattern, the wells of the reduction and drilling are complemented by polymer flooding, and the mining of high permeability layers in Saertu; the second set is the second infill well pattern in the Saertu thin-difference oil reservoir was exploited to make use of the original Sa and Pu high I secondary infill well to seal the tertiary oil recovery layer in the Pu oil reservoir and the second oil reservoir, narrow the well section, and form a Well network linear 250m after injection. The Pu II and Gaotaizi reservoirs were also adjusted to two sets of layers: the first set of infill wells for the low-permeability layers of the Portuguese II to the Gao-I9 was used to block the upper Saertu The lower high I10 and lower reservoirs are drilled and transferred to form a 250m five-pointscheme; the second is used to mine the secondary wellbore with high I10 and lower permeability layers, using the original Gao II and Gao III secondary infill well. The old wells were filled with high I10-20 oil layers, all the production wells were transferred, and new wells were drilled between the old wells to form a 175m five-point scheme.

After the layer reorganization, the length of the perforation interval in the block decreased from 190.3 m to 75.5 m; the inter-layer permeability differential decreased from 17.7 to 6.1; the ratio of oil-water wells decreased from 2.18 to 1.18; the level of water drive control was increased from 84.8% to 92.5%; multi-way connectivity increased from 31.2% to 56.8%. In the early stage of production of the new well, the daily production per well is 3.5 tons, the comprehensive water content is 95.17%, the daily production of the single well is 2.3 tons and the integrated water content is 95.25% after the block layer reorganization. The initial water injection interval of the injection well is divided into two sections according to the oil layer composition. The new water injection intensity is 6.4 m3/d·m while the old well water injection strength is 7.62 m3/d·m, and the total pressure difference in the block is -0.64 MPa.

2. Determination of water injection parameter

The determination of injection-production parameters after reorganization of block strata is based on numerical simulation methods. Through the study of sedimentary facies, a reservoir geological model is established, and application models such as triaxial structure, microfacies, and phased-attribute properties of blocks are established. The numerical simulation of the reservoir fits the development history of the block, and the fitting accuracy reaches 95%. It lays the foundation for optimizing the water injection parameters and determining the reasonable water injection interval.

2.1. Determination of injection ratio

In the process of oilfield waterflooding, there is generally a phenomenon of high injection-production ratio, which is contrary to the principle of mass balance. In combination with geological features and development characteristics, it is believed that the high injection-production ratio is mainly affected by factors such as ineffective water injection, vertical fractures, elastic water retention, reservoir sedimentation characteristics, and cementing quality. Therefore, it is necessary to determine an actual reasonable ground injected gas/oil ratio for each layer system through calibrate calculations. Taking Saertu second encryption layer as an example, the stratum is 10.07 MPa in the initial stratum pressure after recombiniation. To adjust the pressure system, the stratum pressure will be steadily restored to the original formation pressure of 10.83 MPa year by year, according to Saertu's second encryption.
pressure recovery curve of the stratum, the actual injection-production ratio in the research block should be 1.20, and the actual injection-production ratio in the block ground is 1.51. Then, the ratio of water in the stratum of the stratum is 1.20 / 1.51 = 79.5%, that is, the ratio of water around the strata is (1.51-1.20)/1.51=20.5%. To maintain the original stratum pressure of the reservoir, the injection-production ratio should be adjusted to the theoretical underground value of 1.0. The actual injection-production ratio on the ground is 1.0/0.795=1.26 (Figure 1).

2.2. Determination of subdivision water injection boundary
Combining the characteristics of the remaining oil distribution in the ultra-high water cut period, in order to maximally increase the degree of oil layer mobilization, the research method for the subdivision water injection boundary is to abstract a typical model of 4 injections and 9 mining models in the overall model of the block, with the parameters of each deposition unit. Based on the average value, a theoretical model was established, through adjusting various parameters, the sensitivity analysis was conducted for the relationship between the thickness of sandstone, coefficient of variation, and the final production degree, and a reasonable segmental water injection limit was defined (Figures 2, 3, and 4).

According to the curve of the relationship between the sand thickness, permeability coefficient of variation and the degree of recovery of the water-injection interval given by numerical simulation, it can be found that with the increase of the variation coefficient of sandstone thickness and permeability, the final mining degree gradually becomes smaller, but when the thickness of sandstone is less than 7 meters and the coefficient of variation is less than 0.5, it will continue to become smaller, and the degree of recovery will not increase significantly. Considering the benefits and effects, the thickness of sandstone in the water injection interval should be ≤ 7m, and the coefficient of variation of permeability should be ≤ 0.5. The relationship between the number of sedimentary units in the water-injection interval and the difference in the extent of production shows that when the number of deposition units exceeds 4, the
increase in the extent of production difference increases, so it is appropriate to determine the number of deposition units in the injection interval. According to the above-mentioned three parameters determined, combined with the total thickness of each layer system, the number of deposition units, etc., it is determined that the number of water injection intervals should be $\geq 4$.

3. Reasonable water injection interval

The inter-layer heterogeneity of multi-layered sandstone reservoirs is the main cause of the conflict between layers of water flooding wells. In order to maximize the development effect, the water injection wells should be subdivided to increase the water injection interval as much as possible, but subject to the water injection process., the effect of monolayer limit test water quantity, considering investment and benefit at the same time, and leave room for later adjustment, initially increasing the number of single well water injection intervals to the fourth segment.

3.1 Numerical simulation method

After stratigraphic reorganization, the number of sedimentary units in the Saertu oil layer is 15, the number of sedimentary units in the Pu II to Gao I9 reservoirs is 19, and the number of sedimentary units in the Gao I10 and lower reservoirs is 50. The recovery degree and average permeability of each deposition unit were calculated by numerical simulation. These two parameters were compared with two adjacent sedimentation units, and the composite difference ratios of adjacent deposition units were calculated according to 50% weights. The difference between the Saertu and the Pu II to the Gao I9 reservoirs is within $\pm 20\%$, and the sedimentary units within the $\pm 10\%$ difference in reservoirs with high I10 and below are grouped together.

3.2 Numerical simulation method

The dynamic statistics method is based on the water absorption and liquid production profiles after the reorganization of the block oil and water well layers, combined with the interpretation of the new well flooding. According to the ratio of single-layer water absorption of injection wells, production ratio of single production wells of oil production wells, ratio of sandstone thickness, integrated water content, and the ratio of flooded thickness ratios of new wells (Figure 5), combine the requirements that the number of single-layer injection intervals is not less than 4, we can divide a reasonable water injection intervals in each layer.

3.3 Numerical simulation method

The segmental division of the two methods of the Saertu and the Pu II to the Gao I9 oil reservoirs is consistent with each other. Therefore, the two oil reservoirs are divided into four sections. The adjustment method is determined by the ratio of water absorption and liquid production as well as the water and other indicators according to the recovery degree of the interval. There are certain differences in the segmental division of the two methods of the Gao I10 and lower oil layers. However, combining the dynamic development practice and the oil layer development, it is decided to divide the interval into five segments according to the dynamic statistical method. The same oil and water interval below GII25 is no longer subdivided, GII11 ~ GII24 reservoir segment according to the water content at the end of the production is further subdivided into two sections (Table 1).
4. **Initial application effect**

In accordance with the above method, block A for two consecutive years in 2016 and 2017 adjusted 118 wells, the average number of single wells increased from 2.6 to 3.8, and the new well water injection intensity was adjusted from 6.4 m³/d·m to 6.87 m³/d·m, the old well waterflooding intensity was adjusted from 7.62 m³/d·m to 6.75 m³/d·m, Oil production of per well was increased from 2.1 t to 2.3 t, and the integrated water content decreased from 95.54% to 95.22%. The total pressure drop increases from -0.64MPa to -0.41MPa. The numerical simulation method was used to predict the tracking effect of the stratified reorganization, and based on the current evaluation standard of economic benefits, when the water content in the study area reached 98%, the tracking adjustment of the block A after reorganization of the strata was expected to accumulate 440,000 tons of accumulated oil, and the speed of water content increased slowed down, the final mining rate increased by 1.09 percentage points from the unadjusted rate.

5. **Conclusion**

(1) After the waterflooding development of oilfields in the highly water-bearing period is carried out, the numerical simulation method is used in combination with the reservoir development dynamic empirical adjustment method to effectively establish the water injection parameter standards, reasonably divide the water injection intervals, and improve the development results. The inhomogeneity of the permeability along the wellbore is the main influencing factor for the optimal design of the inflow control parameters in the target section. Also the impact on the inflow profile of the target section is more sensitive than the wellbore pressure drop.
(2) The rational injection-production ratios of the Saertu-based, Saertu-secondary, Pu II-Gao I9, and Gao I10-lower secondary strata after reorganization of the block A strata were 1.13, 1.26, 1.40, and 1.21, respectively; Water flowing boundary 5474: coefficient of variation of permeability is ≤ 0.5, number of sedimentation units in the water injection interval is 4, water thickness in the injection interval is ≤ 7m, number of water injection intervals in single wells is ≥ 4;

(3) The results from the numerical simulation method and the dynamic adjustment method of the Saertu oil layer and the Portuguese II to the Gao I9 reservoirs are in good agreement. The two sets of layers are initially divided into four segments. The results of the two methods with Gao I10 and lower oil layers are more different. Large, using the reservoir dynamic method is initially divided into five segments.

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Acknowledgements
This work was supported by the National Natural Science Foundation of China [grant number 51474070].

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