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Study on Water-Driving Law and Remaining Oil Distribution Pattern in Ultra-low Permeability Reservoir

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Abstract: The water-cut rises quickly and the remaining oil distribution is complex when the ultra-low permeability reservoir enters the high water cut stage. The comprehensive use of reservoir engineering, dynamic monitoring, numerical simulation, core experiments and other methods, this paper systematically summarizes three types of water-driving law and distribution characteristics of remaining oil, which are pore-fracture flow, pore-fracture flow and fracture flow. It is considered that the horizontal water drive is mainly controlled by material source, well pattern and fracture, while the vertical water drive is mainly controlled by reservoir heterogeneity, water line distance, injection-production well distance, etc. , the patterns of residual oil formed by different types of percolation are different, in this paper, 7 macroscopic patterns of remaining oil distribution, such as well pattern control, heterogeneity control, single sand body connected control, longitudinal interference, injection-production non-correspondence and non-main reservoir unutilized, are summarized, in the light of different remaining oil patterns, the paper puts forward the adjustment direction of tapping potential, such as optimizing injection-production structure, optimizing injection-production mode.

1 Introduction

The ultra-low permeability reservoirs face problems such as accelerated water cut increase, increased difficulty in stabilizing production, and complex and difficult to predict remaining oil distribution after entering the medium to high water cut stage. By studying the water drive patterns and remaining oil distribution characteristics of typical ultra-low permeability reservoirs, technical support is provided for formulating injection and production control measures during the high water cut stage of ultra-low permeability reservoirs and further improving oil recovery.

2 Type of seepage

According to the characteristics of reservoir development, the seepage types of ultra-low permeability reservoirs are divided into three types: pore type seepage, pore fracture type seepage, and fracture type seepage. Taking WY district of Ansai oilfield as an example, the characteristics of pore type seepage are characterized by relatively uniform injection of water around, slow increase in water content in oil wells, a low water content period of over 4 years, an average water line advancing speed of less than 0.2m/d, an average cumulative oil production of over 14500 tons per well, and a high degree of water drive storage utilization; The characteristics of fracture type seepage are mainly manifested as the development of micro cracks, with injected water protruding along the cracks. The water content in the main oil well increases rapidly after water is seen, with a water breakthrough period of 6-12 months. The water line advancement speed is greater than 0.5m/d, and the average cumulative oil production of a single well is about 5000 tons. The lateral oil well shows slow or no effectiveness, and the water drive condition is poor; The characteristics of pore fracture type seepage are characterized by a water cycle of about 2 years, a water line advancing speed of 0.2~0.5m/d, and an average cumulative oil production of about 8800 tons per well.

3 Water drive pattern

3.1 Planar water drive pattern

For porous flow reservoirs, water flooding is relatively uniform on the plane, with a long low water cut period and a wide range of water injection. When the water flooding front reaches the oil well, the rate of water cut increase is significantly accelerated. Taking the WLW Chang6 reservoir in Jing'an oilfield as an example, the low water cut period lasts for 8 years, and the recovery rate during the low water cut period is nearly 15%. After the water cut reaches 40%, the water drive front edge breaks through 300m, and the water cut in the oil well increases rapidly [1].

Pore fracture percolation reservoir, taking the WY Chang6 reservoir in Ansai oilfield as an example, it has a

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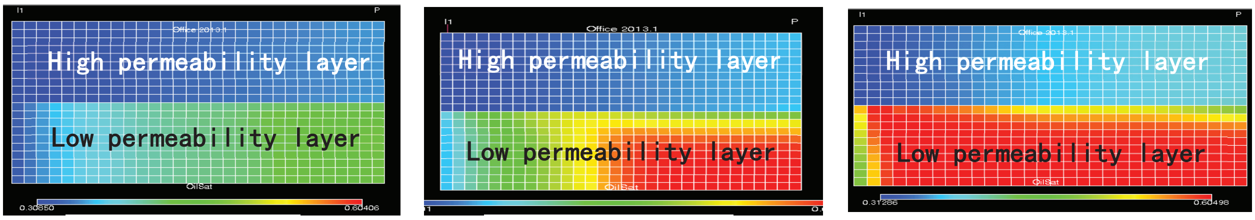
low water cut period of about 4 years. The plane water drive sweep range is irregular elliptical, and the long axis direction is the dominant direction of water drive, mainly controlled by the source and fractures. The sweep range is large, while the short axis direction is the lateral direction of the fractures, and the sweep range is relatively narrow

For a unidirectional fractured seepage reservoir, taking Ansai oilfield S160 as an example, the water line direction is basically consistent with the maximum principal stress direction. The main oil well sees water quickly, and the difference in main lateral pressure reaches over 5.6MPa. The lateral water drive range is narrow, and the lateral water drive width is 60-100m after 10 years of water injection development. After 20 years of water injection development, the lateral water drive width reached about 120m, with obvious unidirectional striped water lines [2], and the remaining oil was distributed on the lateral side of the water line.

3.2 Longitudinal water drive pattern

3.2.1 Affected by reservoir heterogeneity, the intervals with relatively good physical properties are the main washed intervals, while the intervals with poor physical properties are weakly washed or unwashed

Under the influence of reservoir heterogeneity, injected water is easy to rush along the high permeability zone, resulting in uneven longitudinal application. The layer with relatively good physical properties is the main washed layer, while the layer with poor physical properties is weakly washed or unwashed [3]. Numerical simulation shows that when the permeability difference of the reservoir is 3-5, the water displacement efficiency of the low permeability layer is less than 20%. When the difference is greater than 10, the low permeability reservoir is basically unusable (Figure 1).



(a) Lever different 3 (b) Level difference 5 (c) Level difference 10

Figure 1. Numerical simulation of reservoir dynamics under different grades

The core combination experiment shows that when the grade difference of the core is less than 3, the oil displacement efficiency of the combination model is not significantly different from that of a single core, but the oil displacement efficiency of the combination core with a grade difference>3 is significantly lower than that of a single core.

3.2.2 Longitudinal staggered distribution of layers with different water flooding levels

By comparing and analyzing the inspection well data of three typical ultra-low permeability oil reservoirs, it can be seen that the main reservoir has good physical properties and high degree of utilization, The degree of water washing is mainly medium to strong water washing, and the oil saturation of the reservoir decreases by 13% to 25%, but there is residual oil in thin-inter beds. The average thickness of the strong water washed reservoir is 3.0m, accounting for about 15.3%. The average thickness of the water washed section in the reservoir is 9.2m, accounting for 51.4%. The weak to unwashed reservoir is mainly the section with poor physical properties, and the oil saturation decreases by 2-5%. Therefore, the middle to unwashed section of the reservoir is still the main section for tapping remaining oil in the future.

3.2.3 The closer the distance from the water line and water injection well, the stronger the water washing thickness of the reservoir, and the higher the oil displacement efficiency of the reservoir

Comparing the four inspection wells in the w34-029 well group, it was found that the distance between wj34-0292 and the water line and injection well was the smallest. The oil displacement efficiency of this well was the highest, reaching 35.7%, with a strong water washing thickness ratio of 52.9%, a medium water washing thickness ratio of 43.2%, and The weak to unwashed ratio of only 3.9%.

4 Macro residual oil distribution characteristics

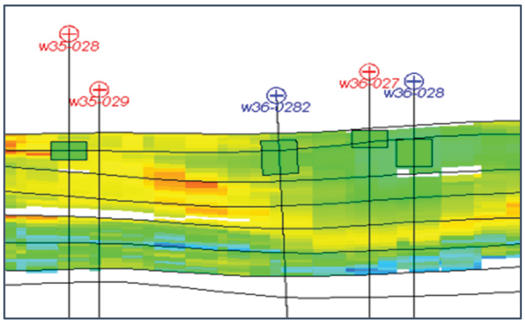
Through the study of water drive patterns in different types of ultra-low permeability reservoirs, it is believed that there are seven patterns of macroscopic residual oil.

4.1 Residual oil on the plane

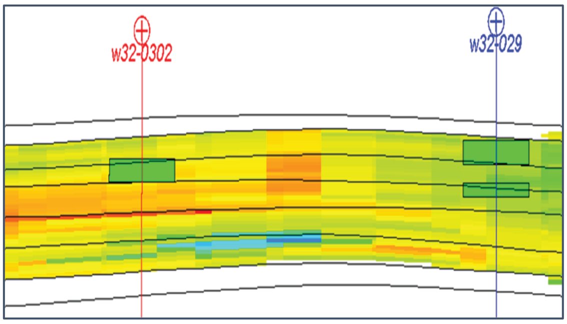
There are four patterns of residual oil distribution in the plane [4]. One is the well pattern control type, which mainly exists in reservoirs with relatively uniform planar water drive, and the remaining oil is mainly distributed in clusters or triangles at the corner wells of the well pattern. The second type is fracture control, where the main direction of the fractured reservoir is to form a row shaped water injection after the oil well is flooded and converted into injection. The injected water flows laterally along the water injection well, and the remaining oil is mainly distributed in strips between the oil wells on the side of the water line. The third type is heterogeneity controlled type [5], which is influenced by plane heterogeneity. Water is injected into areas with poor physical properties to flow around, and remaining oil is distributed in isolated islands and enriched in low permeability areas between oil and water wells. The fourth type is the single sand body connectivity control type. The contact relationship between single sand bodies is different, and the degree of reservoir connectivity is different. The contact connectivity between single river channels, embankments, and distributary bays is poor, and the remaining oil is enriched in clusters.

4.2 Longitudinal residual oil

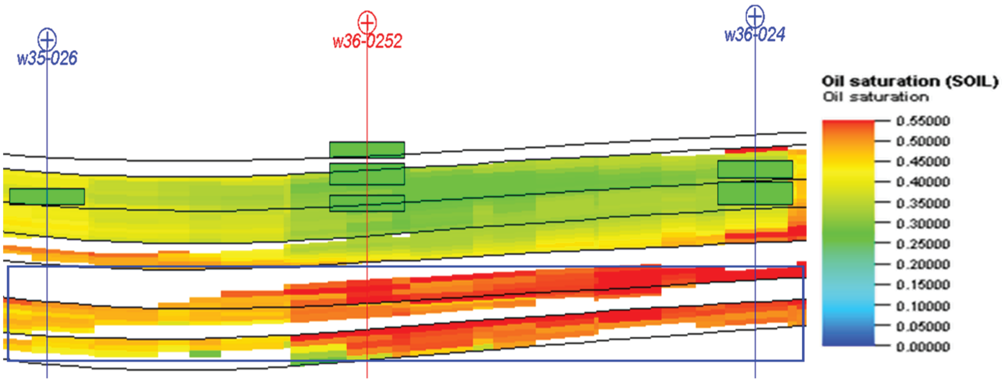
Vertical residual oil can be divided into three modes (Figure 2): firstly, vertical interference type: influenced by heterogeneity within the reservoir, the water washing degree of relatively high permeability layers is high, but there is still thin interbedded residual oil; The low permeability layer has a low degree of production, and the remaining oil is relatively rich, but it is difficult to produce. The second type is the incomplete injection and production type [6] [7]: the single sand body level exists with or without injection, and the remaining oil is enriched near the oil well. The third is the remaining oil formed by the non-main reservoir that has not been developed: the remaining oil formed by the non- main reservoir that has not been developed can be used as a replacement layer for drilling and development in areas with good physical and oil properties



(a) vertical interference type



(b) Incomplete injection and extraction type



(c) Non main layer unused type

Figure 2. Vertical residual oil distribution pattern in ultra-low permeability reservoirs

5 Potential tapping direction for remaining oil

After the ultra-low permeability reservoir enters the medium to high water cut stage, the water drive contradiction further intensifies, the remaining oil is dispersed, and it is difficult to produce. Based on the study of water drive patterns and remaining oil distribution characteristics, this article proposes adjusting the direction of tapping potential by optimizing injection production structure, optimizing injection production methods and utilizing remaining oil in thin-inter beds.

5.1 Perforation adding of oil and water wells, improving the corresponding relationship between injection and production

The stacking types of single sand bodies vary, and the effect of using remaining oil for reservoir perforation [8] [9] is different. The actual results of the mining site indicate that when the cutting and stacking type or the interlayer is not developed, the vertical connection of the single sand body is good, the water injection range is large, and the effect of perforation adding in oil well is poor; The separated vertical connection is poor and can be effectively utilized, making it the main target for adjusting and tapping potential. For example, since 2013, 103 single sand bodies have been perforation added, with an average daily oil increase of 0.54t/d per well. The degree of water drive reserve control has increased from 83.3% to 88.6%.

5.2 Fine layered water injection to alleviate profile conflicts

Layered water injection has shifted from interlayer injection to interlayer injection, controlling water injection for layers with good physical properties and high water washing degree, and strengthening water injection for layers with poor physical properties and low utilization degree, effectively alleviating profile contradictions. For example, in the first district of WLW, 144 wells were divided into layers for injection and supplementary drilling for injection, with the injection rate increasing from 16.4% to 61.8%, the utilization degree of water drive reserves increasing from 64.4% to 69.7%, and the monthly decline of well groups decreased from 0.34% to -0.48%.

5.3 Profile control and flooding to improve water flooding effect

The water content increase pattern of ultra-low permeability reservoirs is mainly S-shaped, with a rapid increase in water content during the medium to high water content period, and the characteristics of multi-directional water breakthrough in the plane are becoming more and more obvious. In response to the existing problems, conducting long-term continuous injection of microspheres for displacement control can achieve good results. Since 2018, 810 well groups of ultra-low permeability reservoirs have been subjected to long-term microsphere flooding, with an annual water cut increase rate decreasing from 5.6% to 1.2%. The effect of stabilizing oil and controlling water is significant.

5.4 Changing the displacement medium to improve oil displacement efficiency

The medium to low water cut period (with a comprehensive water cut of less than 40%) is the main oil recovery period, and the recovery rate of recoverable reserves can reach 45% to 70%. After the comprehensive water cut is 60%, the recovery rate of remaining recoverable reserves is about 15% to 30%, and the water displacement efficiency decreases. Therefore, it is possible to change the displacement medium and use micro residual oil. In 2017, the 17 injection 62 production foam assisted oxygen reducing air drive test [10] was carried out in the middle of WY old area. The production thickness on the injection profile increased, the low-permeability layer was used, the decline of the well cluster was reduced, and the water cut rise was controlled.

6 Conclusion and understanding

The water drive in porous flow reservoirs is uniform and has a wide coverage, while the lateral water drive range in unidirectional fracture flow reservoirs is narrow; As the row spacing and injection production well spacing decrease, the degree of water flooding increases; Affected by reservoir heterogeneity, vertically different water flooded levels of layers are staggered, and the middle to unwashed sections are the main sections for tapping potential for remaining oil.

Seven distribution patterns of macro residual oil were identified based on different origins: well pattern control, fracture control, heterogeneous control, single sand body connectivity control, vertical interference, injection production mismatch, and non-main reservoir undeveloped.

On the basis of fine characterization of single sand bodies and fine description of remaining oil, the main technical directions for tapping the potential of remaining oil in high water cut stages of ultra-low permeability oil reservoirs are perforation adding of oil and water well, fine layer injection, profile control and displacement control, and changing displacement media.

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