Variation Rules before and after Water Flooding in Ultra-low Permeability Reservoir

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Abstract: After long-term water injection and erosion in water drive development reservoirs, the physical properties and seepage of the reservoir will change significantly, resulting in complex groundwater flooding laws and difficult adjustments to oilfield development. Based on the actual core data of inspection wells, this paper studies the changes in the physical properties and seepage characteristics of ultra-low permeability reservoirs after long-term water flooding and their effects on oilfield development. Growth, particle migration, and the illiteization of clastic rocks make the average porosity of the reservoir change little, the permeability declines greatly, the acid-sensitive minerals in the interstitial decrease, the water-sensitive and speed-sensitive minerals increase, and the relative permeability curve is medium the bleeding point shifts to the right, and the wettability changes to be hydrophilic.

1 INTRODUCTION

Water injection development is currently the most commonly used and most economical and effective development method for oil fields. However, long-term water injection development will cause increased changes in reservoir physical properties, pore roar structure, seepage characteristics, wettability, etc., and changes in reservoir parameters will affect oil and water. The seepage law and remaining oil distribution affect the oilfield development effect (Li et al., 1997; Wang et al., 1999; Zhang et al., 2005; Li & Xu, 2003). Therefore, studying the changing laws of reservoir physical properties, seepage flow and other characteristics before and after water flooding is of great significance for reservoir development adjustment and enhancement of oil recovery.

2 VARIATION LAW OF RESERVOIR CHARACTERISTICS

After long-term water flooding, reservoir characteristics will change, and reservoirs with different physical properties have different changing laws. In order to study the characteristics of ultra-low permeability reservoirs after water flooding, the actual core samples of 8 inspection wells in the inspection well group in the area A of the ultra-low permeability typical oil reservoir were selected for porosity, particle size, full-diameter core analysis, relative permeability, analysis and testing of mercury intrusion and wettability. At the same time, in order to ensure the research results, the core samples covered 8 inspection wells with different water flooding directions and different injection-production well spacings, and for the comparability before and after water flooding for the cores of the same well number, try to choose the layers with more homogeneous lithology.

2.1 Porosity and Permeability Changes

Domestic oilfields have studied the changes in the physical properties of reservoirs washed by long-term water injection through indoor experiments, coring comparisons, and dynamic monitoring. The results show that the changes in reservoir physical properties are closely related to

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the physical properties of the reservoir itself. Under the same sedimentary microfacies conditions, when the core analysis permeability is above 100mD, the physical properties of the reservoir become better after water flooding, that is, the permeability increase is larger, and the porosity change is smaller; when the core analysis permeability is 1mD<K≤10mD, the physical properties of the reservoir become worse after water flooding, that is, the permeability becomes smaller and the porosity increases or changes little.

The core analysis permeability of the test area is $1.42\times10^{-3}\mu m^2$, which is a typical ultra-low permeability reservoir. 245 core samples from 8 inspection wells were selected for routine physical property analysis and compared with the core data from the initial development of the well group. The results showed that after long-term water flooding, the porosity and permeability of the reservoir decreased to a certain extent. The average drop in porosity is within 5.0%, and the overall change is not significant, but the drop in permeability is relatively large, mainly concentrated in 15-35% (Table 1).

Table 1: Comparison table of porosity and permeability changes before and after water flooding.

Level	stage	Φ (%)			K ($10^{-3}\mu m^2$))		
		Number of samples (pieces)	Average (%)	decrease (%)	Number of samples (pieces)	average($10^{-3}\mu m^2$)	Decrease (%)
N1	Before	573	12.6	4.8%	573	1.58	33.2
	After	742	12.0		742	1.05	
N2	Before	543	12.9	1.0%	543	1.13	17.2
	After	772	12.8		772	0.94	

2.2 Pore Structure Changes

Wells W433 and Y180 and wells QJ011-353 and QJ011-354 respectively represent the pre-wash and post-wash stages. The test results show that after water flooding, the sorting coefficient, variation coefficient, and average value of the pore roar distribution parameters all show an obvious downward trend, indicating that during the reservoir water flooding process, the migration of microscopic particles blocks some pores and roars, making the hole roar tend to Uniformity, the microscopic heterogeneity of pores is weakened; permeability, pore volume, and median radius of the pore size characteristic parameters are reduced, and the pore radius is complicated after water flooding. The drainage pressure and median pressure of the pore connection characteristic parameters increase Large, the mercury inlet saturation and mercury removal efficiency decrease, indicating that after the reservoir is flooded, the pore connectivity and seepage ability becomes worse, and the reservoir capacity becomes smaller (Table 2).

Table 2: Comparison table of hole roar characteristic parameters before and after water flooding.

stage	well	Φ (%)	K ($10^{-3}\mu m^2$)	Pore volume (cm^2)	Sorting coefficient	Coefficient of Variation	Discharge pressure (MPa)	Median pressure (MPa)	Median radius (um)	Maximum mercury saturation (%)	Mercury removal efficiency (%)
Before	W433	13.6	1.2	1.5	1.8	0.19	0.57	6.49	0.16	80.3	31.5
	Y180	15.1	1.3	1.7	1.6	0.17	0.99	8.51	0.11	87.0	36.3
	average	14.3	1.3	1.6	1.7	0.18	0.78	7.50	0.13	83.6	33.9
After	QJ011-353	13.2	0.9	1.2	1.3	0.18	0.81	7.51	0.10	76.6	27.2
	QJ011-354	12.4	0.5	1.5	1.5	0.15	1.12	10.21	0.14	80.8	28.8
	average	12.8	0.7	1.4	1.4	0.17	0.97	8.86	0.12	78.7	28.0

From the comparison curve of core mercury injection of exploratory wells (before water flooding) and inspection wells (after water flooding), the starting pressure of samples after water flooding increased significantly, and the flat section of the curve also changed significantly. Compared with before water flooding,the mercury ingress curve of the latter sample became significantly steeper, and the mercury withdrawal curve also had the same law, indicating that the pore structure of the reservoir has increased after water flooding, the overall permeability has decreased, the seepage capacity has weakened, and the pore roar structure has become more complex (Figure 1).

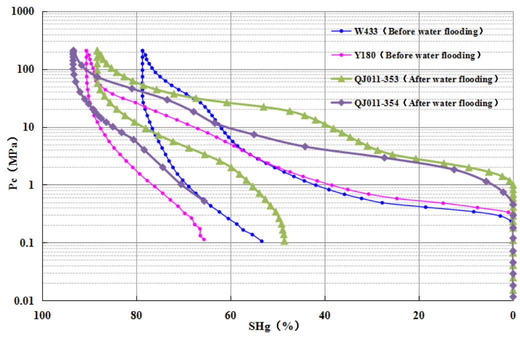

Figure 1: Comparison of typical mercury injection well curves before and after water flooding.

2.3 Phase Permeability Changes

Using core samples from 13 exploratory wells in the test area and 36 inspection wells to carry out water flooding tests, and normalizing the test results, the results showed that after water flooding, the irreducible water saturation increased from 33.1% to 34.5%, with residual oil saturation increased from 26.7% to 30.7%, oil-water two-phase seepage range narrowed from 40.2% to 34.8%, water saturation at isotonic point increased from 57.2% to 59.1%, and oil displacement efficiency decreased from 55.0% to 50.9 % (table 3).

Table 3: Comparison table of phase permeability data before and after water flooding.

stage	Irreducible water saturation (%)	Residual oil saturation (%)	Interval range (%)	Isotonic saturation (%)	Isotonic permeability ($10^{-3}\mu m^2$)	Oil displacement efficiency (%)
Before	33.1	26.7	40.2 (33.1-73.3)	57.2	0.13	55.0
After	34.5	30.7	34.8 (34.5-69.3)	59.1	0.14	50.9

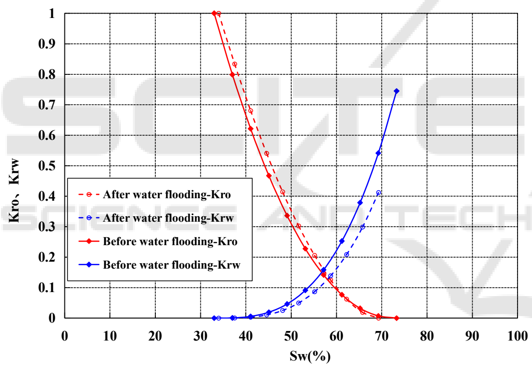

Figure 2: Comparison of phase permeability curves before and after water flooding.

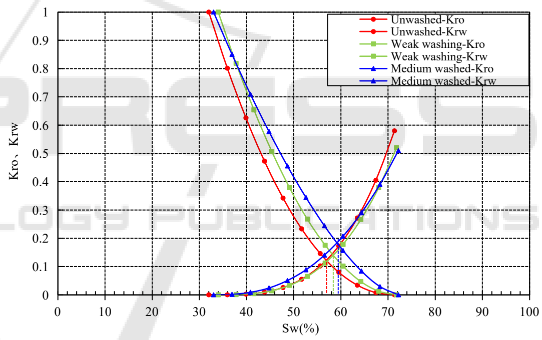

Figure 3 Comparison of phase permeability curves of different water-washed intervals

Judging from the normalized phase permeability curves of the core water flooding test before and after water flooding, the isotonic point of the sample after water flooding moved to the right, indicating that the wettability of the rock after long-term water flooding changed to more hydrophilic (Figure 2); And there is a certain difference in the relative permeability curves of cores with different washing degrees, that is, the higher the washing degree, the higher the isotonic point of the two-phase seepage, the faster the oil and water seepage changes, the faster the water content rises, and the two-phase seepage of the medium-water washing is isotonic The spot is closer to the right than the weakly washed one and is more hydrophilic (Figure 3).

3 CHANGE MECHANISM OF RESERVOIR CHARACTERISTICS

The main reason for the change of reservoir characteristic parameters after water flooding is caused by the interaction of injected water with reservoirs and fluids during the water injection development process (He & Xu, 2010). The changes are mainly manifested in the migration of formation particles and changes in clay minerals. It is the hydration and expansion of clay minerals, and the continuous erosion will cause the stratum particles to fall off, migrate and block pores or roars. This is particularly prominent for ultra-low permeability reservoirs with high clay mineral content; secondly in the long-term water injection process, some authigenic microcrystalline minerals will accumulate in the pores or roars, blocking the roars, resulting in enhanced reservoir heterogeneity; at the same time, due to the chemical reaction between the injected water and underground minerals, some clastic rocks Yili petrification increased the content of water-sensitive minerals in the reservoir, resulting in weakening of the reservoir's seepage capacity (Figure 4, Figure 5).

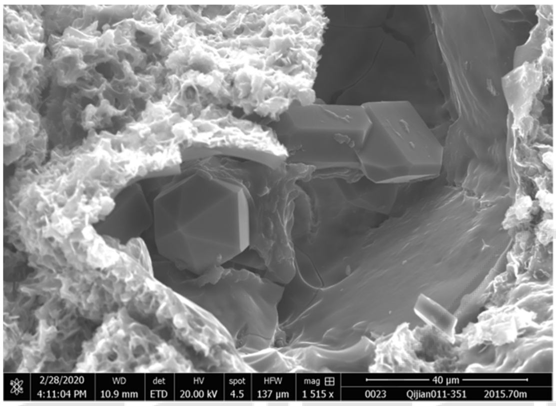

Figure 4: The remaining dissolved pores are filled with authigenic quartz.

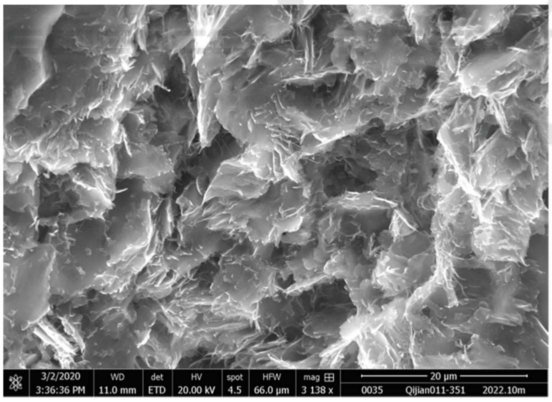

Figure 5: Yili petrochemical alteration of clastics.

At the same time, studies have shown that the degree of cementation between different clay minerals and rock particles is very different. Chlorite is generally attached in a film-like form or surrounds the particles. Its crystallite structure is relatively strong and is not easily damaged during water injection. After flooding, the water cut declines slightly (2-5%). The content of clay minerals varies greatly. The illiteization of clastic rocks causes the content of illite to increase by 6-8%. The Yi/Meng interlayer has strong water swelling properties, resulting in a substantial increase in content. The relative content increases from 5% increased to 14-16%; these clay minerals have different reaction mechanisms during water flooding, so the damage to the formation is also different. Among them, the illite and the mixed layer of I/M are water-sensitive minerals, and the damage to the bottom layer is mainly due to water Swelling, blocking the roar; kaolinite is a speed-sensitive mineral, which is mainly manifested as migration and blockage during the water flooding process, and is affected by the reservoir water flooding speed and intensity; Chlorite is an acid-sensitive mineral, except for transportation In addition to migrating blockages, other deposits can also form under the action of acid to damage the formation (Peng et al., 2006; Gao, 2003).

The wettability is an important characteristic of the interaction between rock and fluid, and it is also the basis of whether the injected fluid can drive oil. In the water injection development process, the wettability of the rock can have an important impact on the water flooding process, but long-term water flooding can also change the wettability of the rock. The wettability change is mainly caused by the fluid in the porous medium. It is determined by factors such as the flow of water, the injection of water, the production of oil and water, and the changes in the physical and chemical properties of oil-water-rock (Ji et al., 2009). During the oilfield water injection process, with the extension of the development time, a relatively strong water-rock reaction will occur in the reservoir. Particles and interstitials will generally dissolve, break and migrate under the action of the injected water, resulting in the reservoir variety. On the one hand, because the oil film on the particle surface is scoured and migrated, more hydrophilic rocks are leaked; on the other hand, the temperature, pressure, formation water, crude oil composition and oil saturation of the formation have all changed, which together affect wettability. The test data also shows that when the water saturation of the oil layer is greater than 40%, the wettability of most of the rocks changes to be weak hydrophilic. When the water saturation of the oil layer is greater than 60%, it becomes hydrophilic.

4 CONCLUSION

1. During the water injection development process, the reservoir parameters will change significantly. These changes will affect the later development and

adjustment of the reservoir. For the ultra-low permeability reservoir, due to its poor reservoir physical properties, the pore roar structure of the reservoir has deteriorated, the seepage capacity has been weakened, the water-sensitive and fast-sensitive minerals have increased, and the acid-sensitive minerals have decreased. Therefore, during water injection development, the formulation of water injection technology policies should be based on the formation. The critical flow rate is determined, and the fluid that does not exceed the critical flow rate and is highly compatible with the formation for different reservoirs which is injected to help improve the oil displacement efficiency of the reservoir.

2. After water flooding in ultra-low permeability reservoirs, the physical properties of the reservoir become worse, the porosity changes little, and the permeability decreases by about -30%; After water flooding, the displacement pressure and median pressure increase, and the median radius decreases. The maximum mercury inlet saturation and mercury removal efficiency decrease, the microscopic pore structure deteriorates, the water drive efficiency decreases, the oil-water two-phase flow interval narrows, and the isotonic point shifts to the right.

3. Due to the long-term scouring effect of the injected water, the surface of the hydrophilic feldspar and quartz is dissolved and exposed, and the wettability of the rock changes in the direction of "lipophilic, weak lipophilic, neutral, weak hydrophilic, hydrophilic", and the higher the degree of water washing, the more the isotonic point of the two-phase flow moves to the right, and the more hydrophilic the rock is.

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