Research on Seepage Characteristics of Fractured Reservoirs with Low Permeability and Low Mobility

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Abstract. The fluid flowing in the reservoirs is non-Darcy seepage. Moreover, during the driving process, the phenomenon where pores with different diameters participate in the flow in turn is reflected, it shows that water injection development must ensure higher flow porosity and flow saturation in order to achieve better development results. Compared to typical low-permeability reservoirs, the dimensionless oil and fluid index of T oilfield decrease at relatively slow rate when the water cut is less than 20%, the decline rate of dimensionless oil and fluid index when water cut exceeds 20% significantly accelerates, the whole process is approximately linearly decreasing.

Keywords: Ultra-low permeability, oilfield development, seepage characteristics, fracture.

1. Introduction
The permeability of reservoir rocks reflects the condition of rock pore structure to some extent. The research shows the lower the permeability of rock, the smaller the average pore radius of the rock pore system and the more serious the heterogeneous degree, the larger the proportion of the pore volume occupied by the tiny pores, the larger the ratio of boundary fluids in the pore system. These characteristics obviously affect the interaction between the liquid and the solid interface. The lower the permeability, the higher the fluid viscosity, the stronger the interaction of this liquid-solid interface, it will bring about changes in fluid property and complicate the seepage process in low-mobility reservoirs.

2. Single-Phase Seepage Characteristics of Low-Permeability and Low-Mobility Reservoirs
(1) The seepage law deviates from Darcy's law
Generally speaking, when crude oil percolates in low-permeability and low-mobility reservoirs, it shows nonlinear seepage characteristics and has starting pressure gradient. As far as low-permeability and low-mobility reservoirs are concerned, this effect cannot be ignored, it will make the seepage law obviously change and deviate from Darcy's law.

(2) The permeability of the porous media of the reservoirs is variable
As far as low-permeability and low-mobility stratum is concerned, the pore system is basically composed of small pores, when oil and water flow, each pore has its own starting pressure gradient, only the driving pressure gradient is greater than the starting pressure of a certain pore, the oil and water in the porthole begin to flow, at this time, it can increase the permeability value of the whole core.
the continuous increase of the driving pressure gradient, the permeability of the core also increases, and the permeability becomes larger, therefore, the rectangular coordinate system of flow and pressure gradient presents an upturned curve and a straight line, and it means that the permeability increases as the pressure gradient increases and then tends to a constant value.

(3) There is starting pressure gradient

Due to the small pore radius of the low-permeability and low-mobility reservoir, the pores smaller than 1 micron account for a large proportion, and the boundary layer has a significant influence, and the starting pressure gradient appears in the flow process. Moreover, a large number of research data show that the starting pressure gradient is inversely proportional to the permeability, the lower the permeability, the greater the starting pressure gradient.

According to the laboratory testing of core flow and pressure gradient of No.15 in T oilfield, the reservoir presents obvious low-permeability and low-mobility reservoir permeability characteristics, and the fluid flowing in the reservoir is non-Darcy seepage. Moreover, during the driving process, it reflects the phenomenon where pores with different diameters participate in the flow in turn, it shows that the water injection development of T oilfield must ensure high flow porosity and flow saturation in order to achieve better development results.

3. Oil-Water Two-Phase Seepage Characteristics in Low-Permeability and Low-Mobility Reservoirs

(1). Characteristics of oil-water relative permeability curve

According to statistics of oil displacement experiment results of 6 cores in 4 wells in T oilfield (as shown in Table.1), the relative permeability curve reflects the following characteristics: as the water saturation increases, the relative permeability of the oil phase decreases sharply, the relative permeability of the water phase increases rapidly, and as the water saturation increases, the water content increases rapidly.

| well number | core number | layer | bound water saturation (%) | isotonic point saturation (%) | relative permeability of water phase in residual oil | oil displacement efficiency (%) | oil-water two-phase zone span (%) |
|-------------|-------------|-------|-----------------------------|-------------------------------|-----------------------------------------------|-------------------------------|--------------------------------|
| well 1      | 2           | F15   | 52.5                        | 54.0                          | 0.278                                         | 30.5                          | 16.0                           |
| well 2      | 45          | F15   | 51.8                        | 57.2                          | 0.219                                         | 23.2                          | 12.0                           |
|             | 53          | FIII4 | 53.9                        | 57.3                          | 0.288                                         | 38.21                         | 20.6                           |
| well 3      | 16          | FII1  | 47.3                        | 57.5                          | 0.269                                         | 29.6                          | 14.0                           |
|             | 21          | FII3  | 45.4                        | 57.6                          | 0.219                                         | 21.6                          | 9.8                            |
| well 4      | 26          | FII2  | 52.7                        | 55.7                          | 0.281                                         | 33.0                          | 17.4                           |

(2) Change rule of dimensionless oil and fluid index

According to the oil-water two-phase permeability data obtained from the oil displacement experiment, on the basis of Darcy's law, the dimensionless oil and fluid index under different water cut conditions are calculated, the calculation formula is:
In the formula: 

- $K_{ro}$, $K_{rw}$—the relative permeability of the oil-water phase under different water saturations $S_w$ (or water $f_w$); 
- $K_{romax}$—the maximum relative permeability of the oil phase under the condition of bound water; 
- $\mu_o$, $\mu_w$—viscosity of underground oil and water.

According to this formula, the relationship the dimensionless oil and fluid index and between water cut of the T oilfield are calculated (as shown in Fig.1). The results show that the oil recovery index decreases linearly with the increase of water content; the fluid recovery index first decreases and then rises with the increase of water content, but the increase is not large, the dimensionless fluid index is always close to 1, and the liquid extraction space is not big in the later stage.

(3) Analysis and evaluation of oil displacement experiment results

It can be seen from the change rule of dimensionless oil and fluid index that when the curve is concave (Fig.2), it reflects the permeability characteristics of low-viscosity, medium-low-permeability reservoirs. Compared to typical low-permeability reservoirs, the change rule of T oil field is that the decline rate of dimensionless oil and fluid index is relatively slow when the water cut is less than 20%, when the water cut exceeds 20%, the decline rate of dimensionless oil and fluid index is significantly faster in comparison with typical low-permeability reservoirs, and the whole process is approximately linearly decreasing.

Compared to the relative permeability curves, it is found that the relative permeability curves of the 6 cores of 4 wells in the T oilfield all show similar water flooding rules, and the relative permeability curve shape is closer to the fractured reservoir permeability curve (Fig.3). It suggests that the development of natural fractures in the oilfield can promote the reservoir seepage to a certain extent.
4. Conclusion and Understanding

Water injection development must ensure high flow porosity and flow saturation in order to achieve better development results. Therefore, it is necessary to maintain a higher water injection pressure to ensure that more pore crude oil participates in the flow. The existence of natural fractures can promote seepage to a certain extent, but moreover, it is also very easy to cause serious flooding of the reservoir. The next step of scientific research work is how to make good use of existing research results, make the scientific and reasonable water injection policy, while actively playing the role of fractures, avoid serious flooding of reservoir, and achieve efficient and sustainable development of oilfields.

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