Study on Development Characteristics of Low Permeability Oil-water Horizontal Well Area in the Same Layer

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Abstract. According to the development practice of horizontal wells in Putaohua reservoir of low permeability oil-water block, this paper summarizes the development characteristics of the block. At the initial stage of production, the chloride ion value of the near-wellbore formation (i.e., the fluid produced at the initial stage of production) is corrected for the large-scale fractured horizontal wells according to the fracturing fluid that is not returned, so as to judge the water breakthrough property of high water-bearing wells. After putting into production, it is found that the formation water in the block is affected by structure and lithology respectively. The water injection policies of "strengthening water injection at high position and restraining water injection at low position" and "strengthening water injection at main layer and restraining water injection at communication layer" are adopted to restrain formation water energy from plane and interlayer and reduce water cut in horizontal wells. Based on the theoretical analysis of fracture effect and water breakthrough characteristics of horizontal wells, the theoretical water breakthrough strength and theoretical hydraulic conductivity strength of fractures are calculated respectively, and the chart is drawn. According to the chart, the adjustment idea of "classification cycle water injection, zonal determination of parameters" is implemented, so that the determination of cycle water injection parameters is changed from "fixed strength, fixed cycle water quantity" to "fixed water quantity, fixed cycle water strength", and further improved. The improvement of water injection policy can provide reference for the development characteristics research and water injection adjustment of horizontal wells in the same type of oilfield in the future.

Keywords: Horizontal well, Low permeability, Oil and water are in the same layer, Development characteristics, Chloride ion, Periodic water injection.

1. Problem presentation

With the development of horizontal well production technology, horizontal wells are widely used in producing low permeability and thin interbedded reservoirs. Since the demonstration area for joint development of horizontal wells and vertical wells was put into production, some achievements have been made in the development of horizontal wells in pure oil blocks, but new problems have been encountered in the development of horizontal wells in the same oil-water layer. Studying the
development characteristics of horizontal wells in the same oil-water layer has important guiding significance for the subsequent development of the same type of horizontal wells and water injection adjustment.

2. Geological survey of block
The average porosity and permeability of reservoirs in this block are 14.7% and $2.1 \times 10^{-3} \mu m^2$, which belong to low porosity and ultra-low permeability reservoirs, and the viscosity of formation crude oil is 1.91 MPa s. Original formation pressure is 22.6 MPa, saturation pressure is 6.35 MPa, which belongs to abnormally high pressure reservoir, with developed formation water and complex oil-water relationship.
At the same time, the fracturing scale of horizontal wells in the block is large, the fracturing half fracture is long, the fracture is close to the water well, and injected water is easy to see.

3. Study on development characteristics of horizontal wells in the same oil-water layer

3.1. Division of water breakthrough properties at the initial stage of production
In the initial stage of production, there are many wells with high water content due to the dual influence of formation water and injection water. Due to the complex distribution of formation water in the block, it is impossible to accurately divide the position of oil and water in the same layer only by static data, so it is necessary to divide the water breakthrough property by dynamic data. At present, the data used to distinguish the formation water from the injected water is mainly through testing the chloride ions in the produced water at the wellhead.

The chloride ion value of original formation water tested by exploration well is 4158 mg / L. However, due to the large-scale fracturing of horizontal wells in the block, the amount of fracturing fluid that does not return to the surface is very large, and the chloride ion value of fracturing fluid is very low, which will affect the chloride ion value of the formation near the fracture of horizontal well, resulting in the failure to obtain a higher chloride ion value in the initial stage, whether it is injection water or formation water, which also increases the difficulty of accurately judging the water breakthrough property through the chloride ion value.

Therefore, the formation chloride ion value near the fracture of horizontal well is calculated theoretically as the corrected formation chloride ion value to judge the water breakthrough property. It is found that the chloride ion values of the two wells are basically close to each other and can be used as a reference standard in practical production.

Table 1. Chloride value of formation mixed fluid after horizontal well fracturing

| Conditions of fracturing fluid | Fracturing fluid volume (m³) | Back-flow volume (m³) | Chloride ion of fracturing fluid (mg/L) | Chloride ion of formation water (mg/L) | Estimated chloride ion value after mixing (mg/L) | Measured initial chloride ion (mg/L) |
|-------------------------------|-----------------------------|----------------------|----------------------------------------|----------------------------------------|---------------------------------------------|----------------------------------|
|                               | 2347                        | 436                  | 800                                    | 4158                                   | 2456                                        | 2907                                  |

3.2. Controlling formation water energy by water injection adjustment
After putting into production, it is gradually found through dynamic analysis that the formation water in the block is mainly divided into two types: one is influenced by the structure, the structural line at the lowest part is about -1665m, and the oil-water interface formed along the fault is below. Formation water is developed in all layers, and the energy of formation water in the main layer PI3 is the highest.

In view of this well area, the water injection policy of "strengthening water injection at high position and restraining water injection at low position" is adopted, and the plane adjustment is carried out. At the same time, the swabbing of high water-bearing wells is increased, the energy of formation water body is weakened, and the extrapolation of formation water is restrained. Second, due to the influence of lithology, the same layer of oil and water develops locally in the PI4 and PI5 layers with poor physical properties. When the horizontal well undergoes cross-fracturing, it will communicate with the formation
water layer, resulting in high water cut after commissioning. For this kind of horizontal wells, the water injection policy of "strengthening the water injection in the main layer and restraining the water injection in the communication layer" is adopted, and the interlayer adjustment is carried out. By adjusting the formation pressure between the two types of layers, the output of the communication layer is suppressed and the water content of the horizontal well is controlled. It is a long-term process to suppress the formation water energy through water injection adjustment. After more than two years of adjustment, the formation water energy of the block has been significantly reduced, and the water content of the high-level horizontal wells has been controlled.

3.3. According to the water injection chart, cyclic water injection is carried out in different areas

The physical properties of the formation in the block are poor, the matrix permeability is low, and the fracturing scale of horizontal wells is large, and the distance between fractures and wells is close (concentrated between 50-150m). Therefore, the theoretical water breakthrough strength is calculated according to the distance from the well to the seam and the water injection strength (the fingering coefficient is adjusted in combination with the actual water breakthrough strength), and the theoretical pressure conductivity strength is calculated by the pressure conductivity formula, which is drawn into the effective water breakthrough chart. Implement periodic water injection by type, and formulate periodic water injection quantity and water injection cycle by region.

Theoretical water penetration intensity: According to the theoretical water injection volume, calculate the cumulative water injection intensity when the water injection front reaches the horizontal well fracture:

$$Q_J = \pi \cdot L^2 \cdot \phi \cdot S_o \cdot \lambda$$

Where: $Q_J$—theoretical water penetration strength, m$^3$/m
$L$—Injection-production distance, m
$\phi$—Rock porosity, %
$S_o$—Oil saturation, %
$\lambda$—Intralayer penetration coefficient, %

Theoretical pressure guiding strength: According to the pressure guiding formula, determine the cumulative water injection strength when the pressure wave propagates from the bottom of the water injection well to the fracture of the horizontal well during water injection:

$$Q_D = \frac{\mu \cdot C_t \cdot \phi \cdot L^2 \cdot Q_{IW}}{2K}$$

Where: $Q_D$—Theoretical compressive strength, m$^3$/m
$\mu$—Fluid viscosity, mPa·s
$C_t$—Comprehensive compression coefficient, Pa$^{-1}$
$\phi$—Rock porosity, %
$L$—Injection-production distance, m
$Q_{IW}$—Water injection intensity, m$^3$/(m·s)
$K$—Permeability, 10$^{-3}$μm$^2$

When periodic water injection is carried out in different areas, the pressure-guiding water quantity is defined as the effective water quantity, that is, the water injection quantity in each period during periodic water injection. The periodic water injection quantity and water injection period are determined according to the classification of different areas, and then the water injection intensity is deduced. So that the determination of cyclic water injection parameters is changed from "fixed strength and fixed period re fixed water quantity" to "fixed water quantity and fixed period re fixed strength", so as to ensure the transmission of pressure but not water quantity in horizontal wells and prolong the low water cut period of horizontal wells.
Table 2. Water injection method and water volume

| Classification | Partition basis | Partitions | Water injection mode | Stage water injection rate |
|----------------|-----------------|------------|----------------------|---------------------------|
| No well        | According to the plate classification | Strengthened area | Continuous water injection | To pressure-guiding water volume |
|                |                  | Advance adjustment area | Short-term water injection | Periodic water volume = pressure-conducting water volume |
|                |                  | control area | Short-term water injection | Periodic water quantity < pressure guiding water quantity |
| Seen well      | Classified by the number of times of water breakthrough | The first time I saw water, I didn't find out the actual water intensity | Short-term water injection | Adjust according to the actual situation with reference to the pressure guiding water quantity |
|                |                  | See water many times | Short-term water injection | Refer to previous water breakthrough |

Table 3. Classification of water injection cycle of short-period water injection wells

| Classification               | Water injection cycle | Remarks                                                                 |
|------------------------------|-----------------------|-------------------------------------------------------------------------|
| Well with large overinjection quantity | On 1 off 2            | There is more water in the formation, and the water drive speed is fast, which reduces the water volume and increases the dialysis intensity |
| Well to be debugged          | On 2 off 1            | Accurate water distribution is required between layers                   |
| Other wells                  | On 1 off 1            |                                                                         |

4. Knowledge gained
1. Affected by large-scale fracturing, the chloride ion value of horizontal wells will be obviously disturbed at the initial stage of production, so it is necessary to calculate the chloride ion value of the formation near the fractures of horizontal wells by theory as the corrected chloride ion value of the formation to judge the water breakthrough property.

2. For horizontal wells with large fracturing scale and long fracture length, the theoretical chart can be established by calculating the theoretical water breakthrough strength and the theoretical hydraulic conductivity strength, and periodic water injection can be carried out in different zones.

3. By defining the pressure-conducting water volume as the effective water volume, and formulating the periodic water injection volume and water injection cycle by zoning and classification, the determination of periodic water injection parameters is changed from "constant intensity, constant period, and then constant intensity", thus ensuring the pressure transmission of horizontal wells but not the water transmission, and prolonging the low water cut period of horizontal wells.

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