Experimental study on asynchronous injection-production in horizontal well area of low permeability reservoir

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Abstract. Since 2006, a horizontal well area of low-permeability reservoir has experienced the stages of water injection efficiency and comprehensive adjustment after water breakthrough, and the formation pressure has gradually recovered. The relation curve between water cut and recovery percent shows that the development effect of horizontal well zone is obviously better than that of vertical well zone. However, with the increase of the number of the water breakthrough horizontal wells and the adjustment times, the water injection cycle is gradually shortened and the water control cycle is extended. At the same time, the adjustable direction is reduced after water breakthrough, and the contradiction between water supply and water cut is prominent. It is very difficult to stabilize the liquid and control the water in the water cut stage of the horizontal well by conventional single water injection adjustment. Therefore, asynchronous injection-production test is carried out for horizontal wells with multi-stage and multi-direction water breakthrough. It adopts the method of "no production during injection and no injection during production", plays the role of "dialysis production and effective displacement", reduces the water cut of oil wells, and excavates the remaining oil between wells. Through numerical simulation and comparison of different injection and production cycle schemes, and through multiple rounds of field tests, the injection and production parameters of asynchronous injection and production tests are continuously optimized as injection 3 and production 5. After the horizontal well is opened, the liquid supply capacity of well is enhanced, the remaining oil of matrix is produced, the water cut is reduced to low water cut, and the oil is increased averagely by 222t of single well, which has achieved good results. It can provide reference basis for water flooding adjustment for the same type of reservoir in the future.

Key words: Low-permeability reservoir; Horizontal well; Asynchronous injection-production; Steady liquid water control; Remaining oil; Injection-production parameters.

After water injection in a horizontal well block in a low-permeability reservoir, the horizontal well gradually became effective, and its output remained more than 3 times of that of the surrounding vertical wells, and the development effect was obviously better than that of the vertical well development zone. However, as the waterflooding time prolonged, the number of water-cut wells increased, a total of 16 horizontal wells saw water quickly after the effect, and the water cut increased from 4.7% to 55.7%,
among which 2 wells were flooded completely. After water penetration in horizontal wells, targeted adjustments were made to alleviate the contradiction between water supply and water cut. For single-stage water breakthrough well, control water breakthrough direction and strengthen water injection in non-water breakthrough direction; For multi-stage water breakthrough Wells, Diagonal alternate periodic water injection is adopted to coordinate liquid supply and water cut. Since 2011, the annual implementation cycle of water injection more than 100 times, the horizontal well water cut rise speed has been effectively controlled. However, with the increase of water penetration, it is difficult to adjust and control water injection. After multiple rounds of water injection, the water control cycle was gradually extended, the water cut rising time was shortened after water injection again, and the plane contradiction was intensified. Therefore, with the goal of "stabilizing fluid and controlling water cut", asynchronous injection-production test is carried out on the centralized block of multi-section and multi-direction water breakthrough horizontal Wells, so as to extend water injection period, further restore formation pressure, and at the same time, change the direction of liquid flow, expand the water flooding and its volume, and alleviate the plane contradiction [1].

Fig. 1 changes of the adjustment effect of the horizontal well scheme and the time of water surface again after water injection

1. Principle and parameter optimization of asynchronous injection-production test

1.1. Test principle
Asynchronous injection-production is a special method of periodic water injection, which is applied on the premise that water injection has occurred water channeling and matrix oil has been watersealed. The purpose is to expand the waterflood sweep volume of matrix rocks and improve oil recovery. It is found that oilfield in north China is applied to fractured carbonate reservoir. Liaohe oilfield is applied to fractured bottom water reservoir. Jilin oilfield is applied in the period of high water cut production in the low-permeability block, and the common feature is that it is all used in the vertical well production area [2-3].

Fig. 2 Remaining oil in the low-permeability site is replaced by dialysis in the water-flooded section
1.2. The principle of selecting well
First determine whether the horizontal well water shutoff and injection Wells profile control to achieve the purpose of controlling water cut and increase production. For multi-section multi-direction water well, it is difficult to judge the shutoff layer. For injection Wells with multiple sections of sheet sand, the optimal adjustment period is less than 20 days, the decline rate of surrounding vertical Wells is more than 15%, and the pressure difference between oil pumps is less than 3MPa.

Table 1. Optimization results of asynchronous injection-production well location

| Block       | Average adjusted days (day) | Decline rate around vertical Wells (%) | The oil pump pressure difference (Mpa) |
|-------------|-----------------------------|--------------------------------------|---------------------------------------|
| Channel sand| 14                          | 20.5                                 | 2.0                                   |
| Sheet sand  | 20                          | 15.8                                 | 3.0                                   |

1.3. Water injection cycle and water injection intensity optimization
Petrel software was used to establish the geological model, which was imported into Eclipse software and grid-based. After historical fitting, dynamic data processing, well history data processing and fault processing, a numerical simulation model consistent with the actual geological situation was obtained [7-8].

Compared with depletion recovery, continuous water injection and conventional cycle, asynchronous injection production has a longer stable production period, a smaller decline rate and a higher recovery rate.

In terms of parameter optimization, numerical simulation compared different water injection cycles. Asymmetric short injection and long production had better effects, and the water injection cycle of injection 3 months and close 5 months was preferred. With the increase of water injection, the oil increase, and when the water injection increases to twice, the oil increase effect is the best [9-11].

Table 2. Comparison diagram of recovery percent in different water injection periods

| water injection periods (month)       | recovery percent (%) |
|----------------------------------------|----------------------|
| open one and close one                  | 19.8                 |
| open two and close three                | 20.1                 |
| open three and close five               | 20.4                 |
| open three and close two                | 19.2                 |
| open two and close one                  | 18.3                 |
Fig. 4 variation curve of daily oil with different water injection rates

2. Test well group effect evaluation

2.1. Initial test well
The following conclusions were drawn from the experiment: periodic fluid production increased, single well periodic fluid production increased from 1.6t to 2.6t, and submergence increased from 63m to 94m. The volume of waterflood was expanded, the output of chloride ions increased from 1666mg/l to 1938mg/l, and the residual matrix oil on both sides of the channel was used. Water injection efficiency was improved, water cut decreased from 70.4% to 5.3%, and cycle water production decreased from 180m$^3$ to 45m$^3$.

Table 3. Optimization table of asynchronous injection-production parameters

| The well type       | Cycle optimization (month) | Injection intensity optimization (m$^3$/m.d) |
|---------------------|-----------------------------|---------------------------------------------|
|                     | Phase one                   | Phase two                                  | before the adjustment | after the adjustment |
| water injection well| open 3                      | close 5                                    | 1.4                  | 3.2                  |
| horizontal well     | close 3                     | open 5                                     |                      |                      |

2.2. Internal promotion
In May 2018, on the basis of the good results obtained in the preliminary test, the application scope of horizontal well blocks was expanded, and the asynchronous injection-production test was carried out in 2 selected well groups. In the early stage of development, certain effects were observed after water plugging in horizontal Wells and profile control of water injection Wells. However, with the extension of water injection development time, water was seen in multi-layer and multi-direction, water injection was implemented in a short period, and water injection in the water injection Wells in the direction of fractures was stopped for a long time, and water cut still remained unchanged.

After asynchronous injection and production, the daily production fluid increased by 0.9t and the daily production oil increased by 2.3t, which rapidly reduced to the low water cut, and the cumulative increase of 739t oil was significant.
2.3. **Economic benefit assessment**

Up to now, 22 Wells have been implemented in the horizontal well block of low permeability reservoir. Through the multi-round asynchronous inject-production test, the degree of crude oil production in the deep matrix is improved, and the recovery rate of the well group is improved. At present, the cumulative oil increase is 1110 tons, and the cumulative oil increase is 5000 tons in the estimated effective period. The economic benefit is 2 million yuan according to the calculation of 400 yuan per ton of oil benefit.

3. **Conclusions and recommendations**

1. Asynchronous injection-production can make the residual matrix oil on both sides of the artificial fracture in the fractured section of the horizontal well be used after pressure redistribution, which can improve water flooding efficiency, reduce water cut in the horizontal well, improve oil recovery speed and achieve the purpose of increasing oil by precipitation.

2. Asynchronous injection-production is used to improve the development effect of horizontal Wells in low permeability reservoirs in the late stage of high water cut, which indicates that asynchronous injection-production is a very suitable development method for water breakthrough horizontal Wells and is worth popularizing and applying.

3. To determine reasonable injection-production parameters is the premise of implementing asynchronous injection-production to enhance recovery.

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