Research and application of asynchronous injection-production in ultra-low permeability horizontal well area

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Abstract. When using horizontal wells to exploit ultra-low permeability oil fields, the development effect is usually ensured by increasing the scale of fracturing reconstruction. However, it also leads to the increasing difference of seepage capacity between matrix and fracture, which makes it easier to see water in horizontal wells after water injection and difficult to recover after water cut rises. Therefore, asynchronous injection-production test was carried out in the ultra-low permeability horizontal well area, making full use of the artificial fracture of horizontal well as the high permeability channel, and performing oil-water replacement through full imbibition between high and low permeability layers, so as to improve oil recovery. On the basis of theoretical guidance, during the summary of practice, the main factors affecting the implementation effect of asynchronous injection and production are gradually analyzed, and the reasonable parameters in the implementation process are clearly defined, so as to explore a new treatment method for the middle and high water cut stage in the ultra-low permeability horizontal well area.

Keywords: Horizontal well; Ultra low permeability; Asynchronous injection and production; Medium and high water cut; Infiltration and absorption oil production.

1. Introduction
In recent years, the production scale of horizontal wells in ultra-low permeability blocks has been gradually expanded. In order to ensure the development effect, the scale of fracturing and reconstruction has been gradually increased, which makes it easier for horizontal wells to see water after water injection. With the increasing number of water-seeing cycles, the contradiction between coordinated liquid supply and water cut in well groups has become increasingly prominent. Through the previous periodic water injection adjustment, the adjustment effect has gradually deteriorated, the water control cycle has been gradually extended, and the water cut rising time has been shortened after water injection is resumed again, making it more difficult to control decline. Therefore, a short-period water injection experiment was carried out in Gu A block to explore a new development mode for ultra-low permeability horizontal wells in high water cut period.
2. General situation of geology and development

Gu A block was put into production in January 2016, with 300m×300m staggered five-point injection well pattern, with Putaohua oil layer as the production horizon, 30.52km² of development area, 474.23×10⁴t of geological reserves and 99.59×10⁴t of recoverable reserves. Original formation pressure is 22.6MPa and saturation pressure is 6.35MPa. At present, 193 oil and water wells have been put into production, including 120 oil production wells, with an annual output of 1.8443×10⁴t, an oil production rate of 0.67%, a recovery rate of 4.95%, and an average annual water cut of 48.62%. There are 73 water injection wells, with average daily water injection of 242m³, annual water injection of 3.7055×10⁴m³, monthly injection-production ratio of 1.09, annual injection-production ratio of 0.77 and cumulative injection-production ratio of 1.16.

3. The proposal of asynchronous injection-production mode

3.1. Theoretical basis of asynchronous injection-production

Asynchronous injection-production test is carried out for horizontal wells with multi-section and multi-direction water breakthrough and small oil tolerance pressure difference of surrounding wells. Adopt the method of "no production during injection, no injection during production" and play the role of "dialysis oil recovery+effective displacement" to reduce the water cut of oil wells and excavate the remaining oil between wells. During the period of "no injection during production", horizontal wells are produced and water injection wells are shut down. Through the dual effects of displacement pressure difference and capillary force, the injected water in the high permeability channel and the remaining oil in the low permeability channel in the flooded section are fully exchanged. During the period of "no production during injection", horizontal wells are shut down and water injection wells are opened, and water injection pressure is used to form water injection pressure difference, which further drives the remaining oil in the unwatered section to reduce the water cut of oil wells and further excavate the remaining oil between wells.

Figure 1. The first stage: shut in up dialysis replacement stage

![Figure 1](image1)

Figure 2. The second stage: shut in the well and start up the oil production and depressurization stage

![Figure 2](image2)
3.2. Feasibility analysis of asynchronous injection and production in Gu A block

(1) The scale of artificial fractures in horizontal wells is large, which can give full play to infiltration and absorption

In view of the fact of low permeability and low thickness in Gu A block, in order to ensure the initial liquid production capacity, compared with the previous development of horizontal well blocks, the fracturing scale of horizontal wells in Gu A block has been increased, and the average fracture length of single well has been increased from 145m to 198m, and the fracture spacing has been shortened from 74m to 63m. A large area of artificial fracture provides sufficient space for seepage and absorption for asynchronous injection and production.

**Table 1. Comparison Table of Fracturing Parameters between Gu A Block and Mao A Block**

| Blocks  | Length of horizontal section (m) | Length of oil-bearing sandstone drilled (m) | Gap spacing (m) | Number of fracturing sections (sections) | Single-stage liquid volume (m³) | Single-stage sand quantity (m³) | Half seam length (m) |
|---------|---------------------------------|--------------------------------------------|----------------|-------------------------------------------|------------------------------|-------------------------------|----------------------|
| Mao A   | 631                             | 522                                        | 74             | 7                                         | 248                          | 21                            | 145                  |
| Gu A    | 640                             | 530                                        | 63             | 9                                         | 268                          | 22                            | 198                  |
| The difference | 9                  | 8                                          | -11            | 2                                         | 21                           | 1                             | 53                   |

(2) The water drive distance is close, which is conducive to full pressure suppression

Due to the long half fracture length of Gu A block, under the same well pattern distance of 300m, compared with Mao A block, the average water drive distance from water injection well to fracture is shortened from 178m to 120m, and the average pressure conduction time is shortened from 40 days to 18 days. The pressure of water injection wells is more easily transmitted to the fracture range of horizontal wells, and the bottom hole pressure suppression degree of horizontal wells is high, which is beneficial to give full play to seepage and absorption.

Pressure guiding time formula:

\[ T = \frac{\mu \cdot C_t \cdot \phi \cdot L^2}{2K} \]

In which: 
- \( T \) — Water injection cycle, s;
- \( \mu \) — The viscosity of fluid, MPa. s;
- \( C_t \) — Comprehensive compression coefficient, Pa\(^{-1}\);
- \( \phi \) — Rock porosity, %;
- \( L \) — Injection-production well spacing, m;
- \( K \) — Permeability, \( 10^{-3}\)μm\(^2\).

(3) The remaining recoverable reserves are large and have great mining potential

Gu A block has short production time, fast water cut rising speed, and low recovery degree of horizontal wells, with the recovery degree of 4.95 and recoverable reserves of 23.6% at present. the remaining oil near the fractures of horizontal wells is rich, and there is sufficient potential for seepage excavation.

4. Analysis of main influencing factors of asynchronous injection-production effect

From 2019 to 2020, the asynchronous injection-production test in Gu A block was carried out in 6 well areas, 11 horizontal wells and 25 rounds of single wells. Accumulated oil increase is 531t, and the average cumulative oil increase of single well is 48t, with the effective well number accounting for 63.6%. A total of 11 vertical wells were affected in the well area, and the decline rate decreased by 22 percentage points after asynchronous injection and production. Asynchronous injection-production has achieved good results in Gu A block.
By analyzing the main action mechanism in the asynchronous injection-production process, the fracturing scale, reservoir physical properties, water injection pressure, water flooding degree, pressure-out time and other factors are summarized.

Figure 3. It is positively related to reservoir physical properties, but has little to do with horizontal well drilling

Figure 4. The fracture half length in effective well is about large, and the smaller the water drive distance, the greater the oil increase

Figure 5. Well with low water flooding degree is easier to get good results. If the horizontal well can be effective, the lower the recovery degree, the higher the oil increase
Figure 6. The higher the water injection pressure, the shorter the oil breakthrough time. The larger the water injection rate, the more the liquid production in horizontal wells, but it has nothing to do with the oil increase. (Water injection pressure is more important than water injection rate; The water injection pressure determines the oil breakthrough time, but the oil increase depends on the remaining oil at the infiltration and absorption site)

Figure 7. Well with poor physical properties is easier to suppress pressure, but the oil increase is lower. The oil increase is proportional to the product of water injection pressure and effective thickness, and the wells with poor physical properties must increase the water injection pressure to achieve better results

5. Optimization of asynchronous injection-production parameters

1. Optimization of water injection cycle: Through numerical simulation, the working system of asymmetric short injection and long production is better, and the smaller the half-cycle ratio of boosting/depressurizing, the better the effect. If the ratio is too large, that is, the water injection time is too long, which reduces the cross-seepage of liquid between high and low permeability strips during the injection stoppage, and the oil and water can not be fully replaced, and the effect is close to that of conventional water injection; When the ratio is small, the formation pressure will drop greatly, which will cause serious degassing at the bottom of the well, resulting in the decrease of liquid production and oil production index and the decrease of pump efficiency. Therefore, according to the actual field experience and the results of numerical simulation, the best water injection half-cycle is 30d, the production half-cycle is 90d, and the daily water injection rate in the water injection half-cycle is 4 times of the daily water injection rate of conventional water injection.
2. Optimization of water injection rate: during the implementation of asynchronous injection and production, the working system of short injection and long production has a good effect, that is, water is injected into the formation as quickly as possible in the half-cycle of water injection, and the formation pressure is quickly restored, but the water injection rate is limited by the capacity of the surface water injection system and the formation fracture pressure. Combined with the actual situation of the study block and the optimal water injection cycle selected above, it is recommended that the daily water injection rate of asynchronous injection-production is 3–4 times that of conventional water injection.

6. Conclusions
1. For horizontal wells with large artificial fractures, oil-water displacement can be realized by asynchronous injection and production, which can achieve better oil increase effect.
   2. The main influencing factors of asynchronous injection-production effect are reservoir physical properties, fracturing scale, water flooding degree, water injection pressure, etc.
   3. After the horizontal well enters the middle and high water cut production period, the asynchronous injection and production method should be adopted as soon as possible, and the asymmetric short injection and long production system has the best effect, and the daily water injection rate in the half-cycle of water injection is 3–4 times that of conventional water injection.

References
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Figure 8. Optimization scheme and results of water injection cycle