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Optimization of the Algorithm for Increasing Injection Rate in Water Injection Wells for Pressure Optimization in P Oilfield

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Abstract

In today's society, with the continuous growth of energy demand, Bohai Oilfield, as an important offshore oil resource base in China, is facing increasingly severe challenges while contributing to national energy security. In order to improve the quality of water injection in the oilfield and gradually achieve efficient and stable production, Bohai Oilfield has launched a water injection well pressure optimization project, focusing on improving the efficiency and quality of water injection in the water injection wells, in order to achieve the optimal water injection plan. In practical work, P Oilfield continues to promote the development of water injection well pressure optimization projects, emphasizing practical exploration and continuous optimization of work plans. However, during the project implementation process, there were some problems, one of which was that the statistics of cumulative injection volume were not scientific enough, resulting in a more comprehensive and accurate presentation of the actual results of pressure optimization work. In the context of continuous improvement work, after careful analysis and research, P Oilfield has decided to optimize the cumulative injection rate algorithm to guide the oilfield's water injection work in a more refined way, ensuring sufficient and good water injection, and enhancing the oilfield's production efficiency and comprehensive competitiveness.

Keywords

Offshore Oil Fields, Water Injection Wells, Pressure Optimization, Water Injection Volume, Calculation Method

1. Introduction

P Oilfield has been implementing the optimization plan for water injection well pressure since September 2018. From 2018 to 2020, the increased injection volume for three consecutive years was 600,000 cubic meters, 220,000 cubic meters, and 1.35 million cubic meters, respectively. The reason for the low cumulative injection volume in 2019 is that the wells after acidification failed to timely calculate the pressure optimization injection volume after the acidification effect decreased or even disappeared. Due to the significant decrease in injection pressure after acidification of the water injection well, the effect of optimizing the pressure of the water injection well enters a certain cooling period for a certain period of time, and it is also impossible to separate the acidification injection increase part and the water injection well pressure optimization injection increase part for the increased injection volume afterwards.

The effective improvement of this project will provide more accurate information and basis for P Oilfield to continue promoting the optimization of water injection well pressure in the future. By using more precise methods to measure the pressure optimization of water injection wells, we can guide P Oilfield to strengthen water injection research in a more refined way, and achieve high-quality development of oilfield production.

2. Methodology of Optimizing Water Injection Well Pressure

With the continuous advancement of water injection development in P oilfield, the water injection wells have been blocked in the near wellbore area, resulting in an increase in water injection pressure and a decrease in water injection volume. After multiple rounds of water injection well acidification, the effectiveness of acidification and blockage removal gradually decreases, making it difficult to completely remove the blockage in the near wellbore area. When the maximum pressure at the wellhead of the water injection well remains unchanged, the actual injection pressure at the bottom of the well continues to decrease due to the presence of additional pressure drop. The continuous acidification of water injection wells has brought high measure costs and gradually shortened effectiveness of plug removal, which can no longer meet the needs of oilfield water injection development. After more than ten years of water injection development in P oilfield, this problem has become prominent.

3. Optimization Plan for Water Injection Well Pressure

According to the requirements of the "Offshore Oil Production Engineering Manual" for water injection pressure, the maximum allowable bottom hole injection pressure is 80% - 90% of the formation fracture pressure in the water injection well section. The water injection wells in P oilfield are managed at 85% of the fracture pressure. Optimization of water injection well pressure refers to further increasing the injection pressure of the water injection well after the injection pressure at the wellhead has reached the maximum allowable injection pressure, ensuring safe water injection, and achieving the goal of increasing water injection volume. The key is to determine the additional pressure drop and obtain the extent to which injection pressure can be increased [1].

P Oilfield adopts pressure testing on water injection wells to obtain the water absorption index curve. Through practical verification, it ensures that the inflection point of the water absorption index is determined as the injection pressure of the water injection wells increases, and further obtains the true formation fracture pressure. At the same time, the Hall curve is used to directly calculate the skin factor, thereby obtaining the additional pressure drop situation [2] [3].

This method was first proposed by Hall in 1963, and improved by Boolean et al. in 1989, resulting in an approximate analytical method. The principle is that the Hall curve graph can reflect the different slopes of the straight line segments of water injection wells under different conditions. This slope reflects the changes in seepage resistance of each water injection well, that is, the skin coefficient of each water injection well can be solved from this.

The calculation method of Hall curve slope in the water injection stage is based on the radial flow equation of monomial steady Newtonian fluid, which is plotted on Cartesian coordinate system with Hall integral term and cumulative injection volume R. Before and after water breakthrough in the oil well, they are linear segments, and their mathematical expressions are:

$$R = \frac{0.535626Kh}{\mu_w \cdot B_w\left[\ln\left(R_e/R_w\right)+S\right]}\int(\Delta P)\,\mathrm{d}t \tag{1}$$

$$\int(\Delta P)\,\mathrm{d}t = \frac{1.867\mu_w \cdot B_w\left[\ln\left(R_e/R_w\right)+S\right]}{Kh} \tag{2}$$

$$k = \frac{1.867\mu_w \cdot B_w\left[\ln\left(R_e/R_w\right)+S\right]}{Kh} \tag{3}$$

$$S = \frac{k\cdot(Kh)}{1.867\mu_w \cdot B_w} - \ln\left(R_e/R_w\right) \tag{4}$$

In the formula, S is the skin factor; ΔP is the injection pressure difference of injection well, MPa; R is the cumulative injection amount corresponding to a certain time, m^3; K is the effective permeability, 10^{-3} μm^2; h is the effective thickness, m; R_e and R_w are the driving radius and wellbore diameter, m; t is the time, d; k is the slope of the straight section of the Hall curve; B_w is the volume coefficient of water; μ_w is the viscosity of water, mPa·s.

The skin factor represents the resistance at the bottom of the well. In 1949, Van Everdingen and Hurst introduced the skin effect to characterize the steady-state pressure difference s in the near wellbore region, which is proportional to the skin factor. The mathematical expression is:

$$\Delta P_s = \frac{R\mu_w}{2\pi Kh}S \tag{5}$$

In the formula, S is the skin factor; ΔP_s is the additional pressure drop of Injection well, MPa [4].

Through the above calculations and analysis, the final conclusion is that the optimized pressure of the water injection well is equal to the sum of the maximum pressure at the wellhead of the water injection well and the additional pressure drop:

$$P = P_{max} + \Delta P_s \tag{6}$$

In the formula, P is the optimized pressure of the water injection well, MPa; P_{max} is the maximum pressure at the wellhead of Injection well, MPa; ΔP_s is the additional pressure drop of Injection well, MPa.

4. Optimization of the Algorithm for Increasing Injection Rate Research Results

Using the daily injection volume before pressure optimization in the water injection well as the reference point R_0, gradually increase the injection pressure, with each step of 50 psi and one step every three days. Afterwards, the daily injection volume of a single well R is increased by ΔR. Daily injection volume:

$$\Delta R = R - R_0 \tag{7}$$

In the equation: ΔR is the actual injection increase after pressure optimization of the water injection well, m^3; R_0 is the daily injection volume before implementing pressure optimization in the water injection well, m^3; R is the actual daily injection volume after pressure optimization of the water injection well, m^3.

As the injection pressure of the water injection well is optimized, the allowable maximum injection pressure after overcoming the additional pressure drop is gradually reached. At this point, the increase in injection volume of the water injection well reaches its maximum. The annual cumulative injection volume R_i is the accumulation of daily injection volume:

$$R_i = \sum \Delta R_n \quad (n = 1, 2, \cdots) \tag{8}$$

In the formula: R_i is the cumulative annual injection volume after pressure optimization of the water injection well, m^3; N is the number of days after stress optimization [5].

4.1. Algorithm Optimization

1) Normal situation ($\Delta R > 0$).

After optimizing the pressure of the water injection well, the injection volume continues to increase, and normal daily calculations are sufficient.

2) The water injection volume continues to decrease, and the calculated daily increment is negative ($\Delta R < 0$).

After optimizing the pressure of the water injection well, although the pressure has been increased, the daily injection rate continues to decline, so the reference value for comparison is becoming less and less. This type of well calculates the pressure gradient based on the pressure increase amplitude and includes it in the increased injection rate.

3) Significant decrease in injection well pressure after acidification (Injection pressure < Reference pressure).

After acidification of the water injection well, the injection pressure significantly decreases, which is lower than the injection pressure used as the reference point. The pressure optimization effect temporarily disappears, and will be recalculated when the pressure returns to the reference point.

4) Small decrease in injection well pressure after acidification (Injection pressure > Reference pressure).

The effect of acidification in water injection wells is poor, and the injection pressure is greater than the previous benchmark injection pressure.

Verify the pressure and flow rate at the reference point, and calculate the injection rate according to the pressure and flow gradient.

4.2. Implementation and Benefits of Algorithm Optimization Projects

In 2019, there were 40 pressure optimized water injection wells with a cumulative increase of 220,000 cubic meters. In 2020, there were 74 pressure water injection wells with a cumulative increase of 1.3536 million cubic meters. In 2020, the cumulative injection rate was significantly increased through the implementation of the pressure optimization algorithm for water injection wells. The cumulative injection rate was calculated separately for different water injection wells, more accurately determining the benefits brought by the water injection well pressure optimization project, effectively guiding the next step in arranging the frequency of water injection well acidification and reducing oilfield operating costs.

5. Conclusion and Understanding

The optimization of the pressure optimization algorithm for water injection wells in P oilfield has fundamentally improved the reliability of pressure optimization project data, providing better guidance for the continuous promotion of water injection well pressure optimization projects in the future, and greatly improving the reference value of the data. Clarify the direction for the follow-up water injection work in P Oilfield, effectively reduce the frequency of acidification and other measures, thereby reducing operating costs, and promoting high-quality water injection development in P Oilfield.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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