Quantitative evaluation of water injection composition in high injection-production ratio blocks
-- Taking Chao 5 well block as an example

Guozhong Zhao¹, ² *, Hongwei Wang¹, ², Min Jing³, Xinbao Zheng¹, ² and Zhiguo Fu¹, ²

¹ Exploration and Development Research Institute of Daqing Oilfield Co., Ltd., Daqing 163712, Heilongjiang, China
² Heilongjiang Provincial Key Laboratory of Oil Layer Physics and Percolation Mechanics, Daqing 163712, Heilongjiang, China
³ School of Energy, Chengdu University of Technology, Chengdu 610059, Sichuan, China

*Corresponding author e-mail: zhaoguozh@petrochina.com.cn

Abstract. The injection-production ratio of the oilfields in the periphery of the Changyuan Placanticline is high. The cumulative injection-production ratio of the main oilfields in the Putaohua oil layer is between 1.29-2.46, and the cumulative injection-production ratio of the main oilfields in the Fuyang oil layer is between 1.98-2.65. At present, the viewpoints of high cumulative injection-production ratio and large ineffective water injection are generally concentrated on unmarked reservoir sandstone sections, water absorption by shale, overflow along faults and fracture systems, measurement errors, and pipeline leakage. In response to the above problems, this paper takes the Chao 5 well block as an example, establishes a block-wide numerical simulation model, carries out a quantitative evaluation of the water injection composition of a high injection-production ratio block, and analyzes the main controlling factors of different types of water injection. The research results show that the water absorption of the reservoirs in the North Chao 5- Chao 5 block accounts for 55%, the unmarked reservoir section absorbs 28%, and the mud shale absorbs 8%; the overflow of water drops to 12%. The research content of this article has a certain guiding significance for improving the level of oilfield water injection development and ensuring the efficient and sustainable development of oilfields.

Keywords: high injection-production ratio; quantitative evaluation of water injection composition; invalid water injection; main controlling factors of water injection composition.

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1. Preface
The Chao 5 well area is located in the anticline axis of the Chaoyanggou Oilfield. It is a composite ultra-low permeability reservoir controlled by faults, structures, and lithology [1-2]. Due to its complex geological conditions, the oilfield structure, as well as the unreasonable management method and the restriction of the technological level, have caused that with the extension of the oilfield development time, the overflow water has a direct impact on the comprehensive water cut, the oil recovery rate, and the degree of recovery. The difficulty of high-efficiency development of the reservoir is getting higher and higher [3-5]. Therefore, it is necessary to analyze the reasons for the formation of external overflow and the main controlling factors of the proportion of water absorption in the reservoir section.

In order to solve the existing problems of water drive oilfields, realize effective water injection of water drive development oilfields, and improve the water injection development level of the oilfields, this paper establishes a whole-stratum numerical simulation model of the research block and fits fluid, oil and water production. Carry out a quantitative evaluation of water injection composition in blocks with high injection-production ratio, and analyze the main controlling factors of different types of water absorption. Research shows that the proportion of water absorption in the study area, unmarked reservoir sandstone section, shale, and spilled water is mainly controlled by factors such as the thickness of the unmarked reservoir section, water injection intensity, liquid production intensity, and annual injection-production ratio. The research results of this paper can provide support for oilfield water injection development technology, and are of great significance for realizing effective water injection and ensuring the efficient and sustainable development of oilfields.

2. Analysis of the cause of the formation of injected water
The injection water of low-permeability reservoirs is not completely used to displace the crude oil in the oil layer, but there is a certain amount of invalid injection water, which flows to other places through various channels. There are mainly the following ways of injected water: ① Affected by the characteristics of fluvial facies reservoirs, the distribution of oil sand bodies is small and the lateral changes are large, resulting in an imperfect single sand body injection-production well pattern under uniform well pattern mining conditions, and some sand bodies There is “injection but no extraction” in the body, resulting in a phased or permanent overflow of water; ② The development of natural fractures in the reservoir makes the natural fractures continue to expand, open, and interweave and communicate with artificial fractures, resulting in a large amount of overflowing water in the fractures. And the peripheral boundary pages of the reservoir may cause the injected water to overflow; ③ The longitudinal heterogeneity of the oil layer is serious, and the oil layer is mixed with argillaceous siltstone or silty mudstone, which has certain permeability and pores. Under the condition of high-pressure water injection, due to When betting, spreading or fracturing communication, there is also invalid water absorption. As shown in Figures 1 and 2.

![Figure 1. Schematic diagram of spilled water analysis](image-url)
3. Overview of the work area of Chao 5 block

The Chao 5-Chao 5 North block is located in the Chaoyanggou anticline structural axis of the Chaoyanggou terrace in the eastern part of the Songliao Basin’s central depression area [7]. The block structure is gentle and the top elevation is -920m ~ -680m. There are developed faults within the structure, all of which are normal faults [8]. The strikes of the faults are mainly in the north-south direction, and a few are east-west [9]. The length of the fault is 0.3km ~ 5.0km, and the fault distance is about 10 ~ 80m.

The oil-bearing area of Chao5-Chao5 North Block is 19.0km², with a geological reserve of 1415.1×10^4t. The average effective thickness of a single well in the Chao5-Chao5 North block is 10.9m, and the average number of layers is 6.2. The Chao5-Chao5 North block is divided into three categories according to different reservoir physical properties. Among them, the porosity of the type I oil layer is greater than 17.0%, the air permeability is greater than 20.5×10^{-3}um², and the oil saturation is 58.1% ~ 59.5%. The porosity of the Type II oil layer is 16.0%~17.0%, the air permeability is 10.2-19.3×10^{-3}um², and the oil saturation is 56.5-58.0%. The porosity of the Class III oil layer is less than 16.0%, the air permeability is 5.1 ~ 9.8×10^{-3}um², and the oil saturation is less than 56.2%. It is a low permeability reservoir.

The block was put into development in August 1988. In the initial stage, a 300m×300m inverse nine-point area well pattern was adopted, and the initial average daily oil production per well was 6.0t. In April 1989, it was transferred to water injection development[10]. In 1990, comprehensive measures such as fracturing and pump replacement of wells that were effective in water injection were carried out. The output of the block increased significantly, and the output reached the peak of effective in November 1990. The daily oil production of a single well reached 8.2t, and the oil production rate reached 1.98% [11]. In 1992, the water content of water wells and oil wells began to rise. In August 1993, adjustments to the injection-production system focusing on high water-cut oil wells for water wells were carried out, and linear water injection was gradually realized, which achieved relatively good results. The oil production rate was above 1.2% and stable production for 12 years. After 2000, the water content of the block began to rise, and the decline in output increased. Through the implementation of layered water injection and water injection structure adjustment, periodic water injection, deep profile control, shallow profile control and other comprehensive adjustment measures, the rate of water cut rise has been controlled and the decline in production has been slowed down. Encrypted in 2007 using the "diagonal intersection" method. Good results have been achieved. The daily production level of the block remains stable and the water content remains stable. After 2012, the water content of the block has gradually increased, and the block has entered the stage of fine waterflooding adjustment and potential tapping. In-depth profile control has been carried out to expand the waterflood swept volume, improve inter-layer conflicts, strengthen periodic water injection intensity, improve periodic water injection methods, and control the
increase in block water content. After entering 2018, the block will carry out a second encryption test to further tap the potential of the block.

4. Whole-stratum numerical simulation and water injection composition analysis in the high injection-production ratio block

In order to study the composition of different types of injected water, a numerical model was established based on the coarsening of the geological modeling grid. On the plane, according to the regional geological characteristics of the study area and the well layout method, the uneven step length is adopted on the plane, and the number of grids between wells is more than 5; in the vertical direction, according to the stratigraphic correlation, reservoir division and Physical property interpretation subdivides the reservoir into 46 single layers, each layer adopts an unequal interval grid in the vertical direction, and its value depends on the thickness of each single layer reservoir [12].

The physical map of the numerical model. In addition, the model also includes the formation thickness DZ, porosity, permeability, oil saturation, and reserve distribution. The main reservoir model number: 7/19/22/23 and the sub-major reservoir model number: 9/10/11/17/18.

According to the production data, the fixed liquid volume production is used for history fitting. The overall production history fitting curve is shown in Figure 4 and Table 1. As of March 2019, the actual cumulative fluid production in the Chao 5 well block is 166.04×10^4 m³, and the model calculates the cumulative fluid production 165.64×10^4 m³, which is fitted by the constant fluid production. The actual cumulative oil production is 91.19×10^4 m³, and the model calculates the cumulative oil production is 91.73×10^4 m³ with a relative error of 0.59%; the actual cumulative water production is 74.87×10^4 m³, and the model calculated cumulative water production is 73.91×10^4 m³, with a relative error of 1.28%.

The water injection is fitted with a fixed water injection volume, which is fully fitted (Figure 4).

| Block          | Parameter                | Fitting calculation | Actual Production | Relative error (%) |
|----------------|--------------------------|---------------------|-------------------|--------------------|
| Chao 5 well area | Cumulative fluid production (10^4 m³) | 165.64              | 166.04            | -0.24              |
|                | Cumulative oil production (10^4 m³)    | 91.73               | 91.19             | 0.59               |
|                | Cumulative water production (10^4 m³)  | 73.91               | 74.87             | -1.28              |
Fig. 4 Fitting curve diagram of fluid production, oil production and water cut in Chao 5 well area (2019.3)

Single well-fitting indicators are mainly daily fluid production, daily oil production, water cut, bottom hole flow pressure and water injection volume of water injection wells. Comparing the fitting curves of 65 oil production wells, 58 wells have a good single well-fitting, with a fitting degree of 90%. The fitting curve of some wells is shown in Figure 5. Judging from the above table of overall index fitting accuracy, this time the history fitting of the reservoir is successful, and the numerical simulation prediction model obtained from this is credible.

Figure 5. The fluid production curve of Well 80-86 in Chao 5 well area (2019.3)

According to the results of numerical simulation calculations, in the early stage of production, the reservoirs in the Chao 5- Chao 5 North block accounted for 55% of the water absorption, 28% of the
water absorption of the unmarked reservoir section, 8% of the water absorption of the shale and 12% of the overflow water.

![Figure 6. Variation curve of water absorption ratio of different types of reservoirs in Chao 5 block](image1)

![Figure 7. Water absorption statistics of different types of reservoirs in Block Chao 5](image2)

5. Analysis of main controlling factors of block water injection

The analysis of the water injection composition of the block adopts the gray correlation analysis method. The gray correlation analysis method is a multi-factor comparative analysis method. It is based on the sample wells of each factor and uses the gray correlation degree to describe the strength, size and order of the relationship between the factors. The processing process is as follows:

1. Select the invalid water injection ratio as the reference sequence, and the geological and production parameters as the comparison sequence expressed as:

   \[
   X_0 = \{X_0(1), X_0(2), X_0(3), \ldots, X_0(n)\} \\
   X_i = \{X_i(1), X_i(2), X_i(3), \ldots, X_i(n)\} \\
   X_m = \{X_m(1), X_m(2), X_m(3), \ldots, X_m(n)\} 
   \] (1)

   Where \(X_0\)—reference sequence; \(X_i\)—comparison sequence.

2. In order to ensure that each data has equal polarity and equal weight, it is normalized and dimensionless. The initial value method is used to make the data dimensionless. The calculation formula is:

   \[
   Y_j(k) = \frac{X_j(k)}{X_j(1)} \quad j=0, 1, 2, \ldots, m; \; k=1, 2, \ldots, n 
   \] (2)

   In the formula: \(Y_j(k)\) is the dimensionless sequence.

3. Find the difference sequence, the calculation formula is:

   \[
   \Delta_{0i}(k) = \|Y_0(k) - Y_i(k)\|, \quad i = 0, 1, 2, \ldots, m; \; k = 1, 2, \ldots, n. 
   \] (3)

   Where \(\Delta_{0i}(k)\) —absolute difference.

4. Find the maximum difference and minimum difference between the two levels, the calculation formula is:

   \[
   \Delta_{\text{max}} = \max_i \max_k |Y_0(k) - Y_i(k)| \\
   \Delta_{\text{min}} = \max_i \max_k |Y_0(k) - Y_i(k)| 
   \] (4)

   In the formula, \(\Delta_{\text{max}}\) —the maximum difference between the two levels; \(\Delta_{\text{min}}\) —the minimum difference between the two levels.
The maximum level difference calculated here $\Delta_{\text{max}}=0.881$, and the minimum level difference $\Delta_{\text{min}}=0.001$.

(5) Calculate the correlation coefficient, the calculation formula is:

$$\varepsilon_{0i}(k) = \frac{\Delta_{\text{min}} + \rho \Delta_{\text{max}}}{\Delta_0(k) + \rho \Delta_{\text{max}}}$$

(6)

Where $\rho$—resolving coefficient. Its function is to improve the significance of the difference between the correlation coefficients, $\rho \in (0,1)$, usually takes the value 0.5, the smaller the value of $\rho$, the better the difference between the correlation coefficients.

From the analysis of the main controlling factors of the quantitative evaluation results of water injection composition, it can be seen that the proportion of water absorption in the reservoirs of North Chao5- Chao5 is mainly controlled by factors such as water injection intensity, liquid production intensity, and annual injection-production ratio. The proportion of water absorption in the sandstone section of the unmarked reservoir is mainly controlled by factors such as the thickness of the unmarked reservoir section, fluid production intensity, water injection intensity, and annual injection-production ratio. The proportion of water absorption by shale is mainly controlled by factors such as fluid production intensity, water injection intensity, and annual injection-production ratio. The amount of spilled water is mainly controlled by factors such as water injection intensity, liquid production intensity, and annual injection-production ratio.

![Figure 8](image1.png)

**Figure 8.** Analysis of main controlling factors for the proportion of water absorption in the reservoir section of North Chao 5 block

![Figure 9](image2.png)

**Figure 9.** Analysis of the main controlling factors for the proportion of water absorption in the sandstone section of the unmarked reservoir in the North Chao 5 block
Figure 10. Analysis of main controlling factors of water absorption in mud shale section of North Chao 5 block

Figure 11. Analysis of the main controlling factors of the proportion of spilled water in North Chao 5 Block

6. Conclusion
(1) This paper establishes a numerical model based on the coarsening of the geological modeling grid, and uses constant liquid volume production for historical fitting, water injection is fitted with a constant water injection volume, production data is basically fitted, and the water injection volume is completely fitted, thus verifying The remaining oil distribution law and numerical simulation prediction model are more reliable.

(2) The proportion of water absorption by the reservoir in the North Chao 5-Chao 5 block is mainly controlled by factors such as water injection intensity, liquid production intensity, and annual injection-production ratio. The proportion of water absorption in the sandstone section of the unmarked reservoir is mainly controlled by factors such as the thickness of the unmarked reservoir section, fluid production intensity, water injection intensity, and annual injection-production ratio. The proportion of water absorption by shale is mainly controlled by factors such as fluid production intensity, water injection intensity, and annual injection-production ratio. The amount of spilled water is mainly controlled by factors such as water injection intensity, liquid production intensity, and annual injection-production ratio.
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