Study on EOR method in high water cut stage of low permeability A Oilfield

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Abstract. By using coring, logging, testing data and dynamic data of oil and water wells, the geological recognition, drive system evaluation and remaining oil research after infilling adjustment of different well patterns are carried out, the dominant channel of water drive and the existing position of remaining oil in different well pattern periods. It can be used for reference to improve development effect and oil recovery of other low permeability oilfields in high water cut stage. A Oilfield is a typical low-permeability oilfield, which has the characteristics of poor physical properties, start-up fracture gradient and natural fracture development. After more than 30 years of waterflooding development, the oilfield has achieved good development results through multiple rounds of comprehensive adjustment of water injection wells and oil well measures. But at present, the oil field has entered the high water cut stage, the remaining oil is more scattered, the effect of adjustment means is poor, and the oil recovery rate is reduced, so it is necessary to explore the technical methods to improve the development effect and further enhance the oil recovery. In this paper, the recovery of oil field is evaluated by using the results of indoor core, empirical formula method and reservoir engineering method, and the potential of readjustment of oil field is clarified. Secondly, the reservoir geological recognition and multi-disciplinary remaining oil recognition are carried out, the dominant channel of water drive is identified, the type, existing position and formation reason of remaining oil are clarified, and the comprehensive treatment countermeasures based on the corresponding adjustment and plugging at both ends of oil and water wells are put forward; the application means of periodic water injection is developed, and the cooperation with deep water adjustment and flooding is explored, so as to further expand the affected volume, Methods of EOR. The typical application well area effect has been obviously improved, which provides reference for other low permeability oil fields to improve development effect and enhance oil recovery.

Key words: Low permeability, high water cut stage, enhanced oil recovery.

1. Introduction

Oilfield A, which mainly develops Fuyu oil layer, is a typical low-permeability oilfield with poor physical properties and fracturing gradients. Through multiple rounds of water injection well adjustment and oil well measures after water injection and water injection, the oil field has achieved better development results. However, the current oil field has entered a period of high water content, and the
remaining oil is more dispersed, which makes the adjustment method less effective and the oil production rate lower. Therefore, it is necessary to explore technical methods to improve the development effect and further improve the recovery factor.

2. Evaluation of recovery ratio
This paper analyzes the actual dynamic and static data of 33 community in an oil field through seven methods, including empirical formula method, water drive law curve method, displacement sequence method, logarithmic cycle method, charter curve method, curve method, composite phase permeability method and attenuation method. In addition, this paper separately calculated the recovery factor, combined with the results of indoor core experiments and actual development results, analyzed the applicable conditions of each method to predict the recovery factor, and optimized the recovery factor prediction method.

The empirical formula method of Fuyang oil layer only considers factors such as static reservoir parameters and well pattern density, so it is only suitable for incomplete or irregular production materials at the initial stage of production, and cannot accurately predict the recovery under current production conditions rate. The recovery factor calculated by the logic cycle method is relatively high, and the applicable conditions are oil fields with recoverable reserves exceeding 50% and in a decline stage. In the A1 reservoir, the blocks that meet the applicable conditions of the logical cycle have a reasonable predicted recovery factor. The empirical coefficient values in the Tong Xianzhang curve method come from oil fields with medium and high permeability, which are not universal and are affected by empirical coefficient values, so they are not suitable for ultra-low permeability reservoirs. The composite phase permeability method can reflect the seepage mechanism, and can better reflect the change trend of the nonlinear section of the water drive law (both in the low water cut period and the high water cut period). But the disadvantage is that the calculation of the correction coefficient is more complicated. The descending curve method is suitable for the later stage of water injection development. At present, most of the ultra-low permeability reservoirs in the periphery of Changyuan have not yet entered the late stage of development, so the prediction of oil recovery using this method is not accurate enough. According to the good stability of the calculation results, compliance with the current status of the oil field, on-site practicality and ease of use and mechanism analysis, the recommended oil recovery prediction methods are empirical method, water injection curve method, and composite relative permeability method. When taking the arithmetic average of the prediction results of these three methods, the predicted recovery rate is 26.80%.

Table 1. Applicability evaluation of various recovery factor calculation methods

| Recovery ratio method | Empirical formula method | Water drive law curve method | Displacement series curve method | Logistic cycle method | Tong Charter Curve Method | Composite infiltration method | Decreasing curve method | Average recovery ratio of three methods (%) |
|-----------------------|--------------------------|-----------------------------|---------------------------------|----------------------|--------------------------|---------------------------|-----------------------|------------------------------------------|
| Industry Standard     | 17.09                    | 30.61 (Type A)              | 30.27 (Type S)                  | 32.24                | 35.00                    | 26.14                     | 30.64                 | 26.80                                    |
| Fuyang oil layer      | 23.65                    |                             |                                 |                      |                          |                           |                       |                                          |

At present, the oilfield production rate is close to 20%, the oil production rate is 0.35%, and the water content is 60%. Therefore, it is necessary to explore ways to further improve the development effect and increase the recovery factor.

3. Understanding of fine geology

3.1. The development scale of a single sand body
The Fuyu oil layer mainly develops into large and medium-sized, small-scale low-curved distributary channels and direct distributary channels. In this paper, the well-seismic technology is used to analyze the reservoir, and the well-seismic method to characterize different types of sand bodies is obtained,
which realizes the vertical classification of a single sand layer and recognizes a single sand body from a plane.

Table 2. Research on fine dissection technology of different types of reservoir

| Type of oil layer | Deposition mode                         | Characteristics of sand bodies                                                                 | Key points                                                                 | Well-seismic technology                                                                 | Coincidence rate                                                                 |
|-------------------|-----------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| I                 | Large and medium-sized low-curved diversion channel | Cut-and-stack composite sand body, developed sandstone with large thickness and good continuity | Recognition of single channel boundary in compound meandering zone          | The coincidence rate of single river boundary recognition is over 80%                    |
| II                | Small low-curve diversion channel       | Independent thick sand body with small thickness of developed sand body and poor continuity | Sand and mud boundary and strike determination between wells                | The conformity rate of sandstone over 3 meters in the posterior well is over 80%         |
| III               | Straight diverging river                | Independent narrow sand body with small thickness of developed sandstone and narrow channel  | Prediction of narrow channel                                               | The coincidence rate of 2-3m sandstone in the posterior well is over 70%                |

Type I oil layers mainly develop staggered composite sand bodies. After the well-seismic combined with the fine structure, there are three main types of changes, including the addition of a single channel boundary with a meandering zone, changes in strike and changes in the continuity of sand bodies between wells. The reservoir heterogeneity is enhanced, the sand body is large in scale, and the injection-production relationship is relatively perfect. Independent thick sand bodies are developed in Type II oil layers. After well-seismic combined with fine anatomy, three types of changes appear, including changes in the direction of the channel, and local expansion and contraction of sand bodies between wells. The scale of the sand body is reduced, the continuity becomes worse, and the local injection-production relationship is insufficient. Type III oil layers are developed with narrow sand bodies. After well-seismic combined with detailed anatomy, four types of changes appear, including channel addition and write-off, strike, combination relationship, and length change. The sand body is small in scale, poor in continuity, and imperfect injection-production relationship.

3.2. Quantitative characterization of fracture development characteristics
Identification of single well fractures: The fracture occurrence is described through core, geophysical, laboratory test and dynamic monitoring data. Then, preferentially select conventional logging curves with obvious fracture response characteristics, and establish seven fracture identification modes. The coincidence rate of crack identification in the main layer reaches 70%.

Three-dimensional modeling of cracks: Using the control model of the single well fracture model, under the constraints of related attributes, a three-dimensional fracture network model is established between wells to quantitatively characterize the seepage characteristics of fractures.

3.3. Quantification of the location and type of remaining oil
According to the analysis results of closed coring wells, Type I oil layers are dominated by medium-strong washing at the bottom of the rhythm, with a thickness ratio of 60.8%. Type II oil layers are dominated by middle-weak washing at the bottom of the rhythm, with a thickness ratio of 40.4%. The overall water washing condition of Type III oil layer is poor; From the results of multi-disciplinary remaining oil quantification, the production rates of II and III oil layers are 28.5% and 15.42%, which are relatively low. The remaining oil is relatively rich, mainly including production without injection, injection without production, unidirectional effect and uncontrollable well pattern.
3.4. Identification of dominant water drive channels

According to the research results of sand bodies, fractures and remaining oil, combined with tracer monitoring results, three types of water drive dominant channels are identified. The remaining oil is mainly distributed on the rhythm top of high water flooded layer, the retention zone in the non-dominant waterflooding direction, and the zone of deterioration in physical properties.

In the early stage of block development, the water drive advantage channel has improved the development effect of the stage. However, with the improvement of the block production and the increase of water content, it is necessary to explore methods to block the water drive advantage channel, expand the swept volume, and further improve recovery factor.

3.5. Evaluation method of microscopic oil displacement efficiency

In order to explore ways to effectively improve oil displacement efficiency and increase oil recovery, this paper carried out a photolithographic glass model experiment. Experiments show that the remaining oil in different water-bearing stages of reservoirs with different permeability mainly exists in clusters. With the increase of water content, the proportion of columnar and oil droplet-like remaining oil increases, and the proportion of cluster-like remaining oil decreases, but still above 50%, which is the main type of tapping potential.

Comparing different displacement methods, it is concluded that when the displacement fluid mobility is changed, the displacement efficiency is increased the most when all kinds of remaining oil decrease the most. In addition, when changing the displacement direction and periodically injecting, changing the displacement pressure difference, when the remaining oil drops are the smallest, the oil displacement efficiency is the smallest.

4. Parameter optimization of depth control and drive

Taking the actual injected water of the oilfield as the carrier, and considering the actual pore throat structure and seepage characteristics of the oilfield, the formulation of the deep control and flooding system suitable for fouling and salt-resistant polymer and the injection parameter design method was explored.

4.1. Optimal control and flooding system

The experiment compared the thickening effect and gelling performance of ordinary polymers and salt-resistant polymers, and proved that the salt-resistant polymers have good viscosity-increasing effects and the gel system has a high gel viscosity under the condition of pollution.

4.2. Evaluation of dynamic and static performance of profile control system

Both salt-resistant polymers and gels have good shear resistance, stability and blocking properties.
4.3. Indoor experiment of optimized profile control system
The core flooding experiment was carried out through the artificial three-layer heterogeneous core, and it was concluded that the multi-slug alternate injection method of the 16 million molecular weight salt-tolerant polymer profile control and flooding system is effective. Compared with single-slug polymer flooding and gel profile control, its recovery rate is increased by 5.34%.

4.4. Numerical simulation of construction parameters
Firstly, the injection concentration should be determined. When the injection concentration increases, the drop in water cut increases, and when the concentration is greater than 2000mg/L, the increase in recovery factor decreases. Secondly, the injection volume needs to be determined. When the injection volume is greater than 0.06pv, the increase in oil recovery will slow down. Thirdly, the timing of injection should be selected reasonably. If the profile control and flooding effect is good in the middle water cut stage, the recovery factor can be increased by 4.28%. Finally, the injection method should be determined. When the gel and polymer are injected alternately for two years, the oil recovery effect is the best, and the oil recovery can be increased by 2.19% compared with water flooding. The total recovery factor is 37.50%, and the output-input ratio is 2.134.

5. Conclusion
Through the deep-layer profile control of the block, the dominant water drive channel is controlled, the oil layer production status is improved, the fluid production structure is optimized, and the formation pressure remains stable, which has achieved good economic benefits. The application of this technology has a profound impact on the realization of the sustainable development of oilfields and has broad application prospects.

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