New Method to Quantitatively Describe Remaining Oil by Dynamic Data

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Abstract. Remaining oil description is the core of its research. Although many description methods are available, most of them are qualitative ones. So, this paper introduces a concise quantitative method – “remaining oil dynamic data analysis”, which uses the production performance data to study remaining oil. This method includes five procedures: (1) establish an optimal fitting relationship between cumulative oil production and water cut; (2) determine recoverable reserves through the relationship; (3) determine cumulative oil production by production data; (4) determine remaining recoverable reserves of single wells; (5) draw remaining oil distribution graphs. This method is applied to Hua 201 oilfield remaining oil research, and the result shows good adaptability to high water cut oilfield in late development stage. This method has simple and convenient calculation process and results that are close to field practice, therefore having important application value.

Introduction

In China, waterflood development oilfields have the highest percentage of the world, and most of them have entered the middle and later stages of oilfield development with high water cut[1]. Due to the complexity of geological conditions and the large difference of properties of crude oil, there are still 60%~70% of the oil that have not been produced after waterflood development, which become remaining oil[2,3]. Therefore, quantitative description of remaining oil has become the urgent need of high water cut oil field exploration, and the improvement of oil recovery has important practical significance.

In the late stage of waterflood development, the primitive state of reservoirs has a big change, with the declining oil production and increasing water cut. As the oil/water interface keeps increasing and the water body drives unequally (cusping, tonguing, after flow, etc.), a large number of crude oil is surrounded by water, forming complicate and different blocks of remaining oil[4-7]. It is an urgent need to research the distribution regular of remaining oil and determine the enriched areas for further adjustment of exploration in the late development stage. The remaining oil distribution is not only affected by the heterogeneity of formation, but also influenced by the displacement process, which made it very complex to determine the distribution of remaining oil. However, there are still many description methods of remaining oil, such as: geology, seismology, well logging, core analysis, material balance, water drive characteristic curve and the numerical simulation method, etc.[8]. Although there are many reports of remaining oil researches, the majority are on the qualitative description, while the quantitative description of remaining oil research is relatively small, and the process is more complicated. To solve this problem, this paper presents a concise quantitative method to carry out the study on remaining oil through the single well production performance data – “remaining oil dynamic data analysis”. Application examples show that this method has good adaptability to the late high water cut oilfield, with simple and convenient calculation process, the close results to the field practice, and important application value.

Method and Theory

Due to the long production time, high degree of well control and perfect production dynamic data in the late waterflood development stage, a dynamic production data is used to carry out the
quantitative methods to study remaining oil – “remaining oil dynamic data analysis”, the basic idea is as follows:

1) Establishing an optimal fitting relationship between tired oil and the water cut: the development well tired oil production decreasing, the late high water cut oilfield water cut rising, tired is close to the oil and moisture content. First using the method of mathematics (linear, log, have been, polynomial, index, etc.) to fit the well tired oil and moisture content, optimizing the highest correlation coefficient of fitting relationship as the basis of recoverable reserves prediction;

2) Using the relationship between oil and moisture content to determine the recoverable reserves: according to the tired oil and moisture content, the optimal fitting relationship, predict limit moisture content (0.98), the cumulative oil production, can reserve;

3) According to the production data, statistical tired output: according to the production dynamic data, statistical well cumulative oil production;

4) Determining the residual recoverable reserves: using the recoverable reserves minus the tired oil to determine the remaining recoverable reserves and the remaining oil;

5) Drawing the remaining oil distribution map: according to data from single well remaining oil, residual oil distribution, the implementation of the remaining oil distribution law.

Examples of Application

Oilfield Profile

Hua 201 oilfield is located in the southwest of Shanbei slope of ordos basin, the administrative area belongs to the Huachi county, Gansu province, which is comprehensively controlled by structure and is a shallow buried oil field, and the average buried depth is 1300 meters. The main oil–bearing layers are Mesozoic Lower Jurassic Yan’an Formation Yan 8–Yan 9 oil sandstone reservoir, with the thickness of 70 meters. This oilfield started rolling development in 1999, and it at present has a total of 11 injection wells and 42 production wells, the average spacing is 250 meters, the available oil bearing area is 3.7 km², the available geological reserves are 384.6×10⁴t. After more than 10 years of exploration, Hua 201 oilfield has entered high water cut stage, reservoir average water cut has reached 82.3%. Currently, the high water cut rising speed, the large production decline, the poor overall water flooding effect, the unclear understanding of remaining oil distribution, the unobvious conventional measure effect and many other problems have dramatically increased the difficulty of adjusting exploration.

According to the historical production data of the wells in the oilfield, the reservoir development situation analysis (Figure 1.) shows: Hua 201 oilfield development has experienced three stages, rising stage production during 1998.9–1999.11, stable period during 1999.12–2003.2 and production decline stage for mow. As of June 2012, the average daily oil output is 64.8t, the average daily water output is 300.9m³, the cumulative oil output has reached 80.7×10⁴t , the cumulative water output has reached 93.9×10⁴m³, the cumulative water injection is 167.3×10⁴m³ and the reservoir water cut is 82.3%. In a word, Hua 201 oilfield has high water cut and low daily oil output.

Figure 1. Hua 201 Oilfield production performance curve.
Remaining Oil Distribution

This paper uses “remaining oil dynamic data analysis” to conduct the optimal fitting relationship between the cumulative oil production and the water cut of 42 wells (Figure 2.). Then the author connects the results with the production data to predict recoverable reserves, statistical cumulative oil production and remaining recoverable reserves calculated (Table 1). Based on the single well remaining recoverable reserves, Figure 3 demonstrates the Hua 201 oilfield remaining oil distribution.

![Graphs and images](image1.jpg)

Figure 2. The relation curve of cumulative oil output and water cut.

<table>
<thead>
<tr>
<th>Well number</th>
<th>$R^2$</th>
<th>Recoverable reserve (t)</th>
<th>Cumulative oil output (t)</th>
<th>Remaining recoverable reserves (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hua 201–29</td>
<td>0.9171</td>
<td>78582.5</td>
<td>63287.0</td>
<td>15295.5</td>
</tr>
<tr>
<td>Hua 201–4</td>
<td>0.9437</td>
<td>26334.9</td>
<td>24384.9</td>
<td>1950.0</td>
</tr>
<tr>
<td>Hua 201–5</td>
<td>0.9218</td>
<td>105797</td>
<td>89860.0</td>
<td>15937.0</td>
</tr>
<tr>
<td>Hua 201–6</td>
<td>0.922</td>
<td>26370.4</td>
<td>24359.4</td>
<td>2011.0</td>
</tr>
</tbody>
</table>

It can be seen in Figure 3, Hua 201 oilfield has 8 pieces of remaining oil areas, and the remaining recoverable reserves are $1.13 \times 10^4$ t. Remaining oil distribution are isolated in following 6 areas: (1) Hua 201–12→Hua 201–13→Hua 201–7 wellblock; (2) Hua 201–14→Hua 201–15→Hua 201–16 wellblock; (3) Hua 201–17 surroundings; (4) Hua 201–40 surroundings; (5) Hua 201–50→Hua 201–411 wellblock; (6) degrees 201–51 surroundings, and remaining oil also has 2 area of crumb distribution, numbered as (7) and (8), (7) Hua 201–5→Hua 201–6→Hua 201–201 wellblock; (8) Hua 201–2→Hua 201–4→Hua 201–19→Hua 201–29→Hua 201–361→Hua 201–36→Hua 201–60.

Main Controlling Factors of Remaining Oil

By comprehensively analyzing the structure, sedimentary micro facies, heterogeneity and the relationship between injection–production well pattern and the remaining oil in Hua 201 oil field, it
shows that the remaining oil distribution is mainly controlled by structure. Fig. 4 shows the top structure of the reservoir, it can be seen that reservoir elevation is between 120–160 meters and the reservoir height is 40 meters. The structural highs are in Hua 201–15, Hua 201–3, Hua 201–361 and Hua 201–411 Wells, constructed by four anticlines and three long noses at macro level. The Anticline closed area of Hua 201–16→Hua 201–15→Hua 201–10 is 0.2 km², the structure amplitude is 6 meters, and the high altitude is 141 meters. The Anticline closed area of Hua 201–5→Hua 201–3→Hua 201–53 is 0.55 km², the structure amplitude is 14 meters, and the high altitude is 160 meters. The Anticline closed area of Hua 201–36→Hua 201–361→Hua 201–60 is 0.15 km², the structure amplitude is 10 meters, the high altitude is 152 meters. The Anticline closed area of Hua 201–411 is 0.05 km², the structure amplitude is 8 m, and the high altitude is 152 meters. The three nose structures are Hua 201–7→Hua 201–12 I nose structure, Hua 201–15→Hua 201–16 nose structure and Hua 201–41→Hua 201–50→Hua 201–411→Hua 201–51 nose structure. The respectively plunging directions are NNW, EW and SSW, the magnitude is 6–14 meters, and the length is 300–700 meters.

By contrasting Figure 3 and Figure 4, it shows that remaining oil mainly distributed in the structure of anticline and nose, which means that reservoir structure plays an important role on the remaining oil distribution. This is due to a long nose and anticline is both low potential area for oil and gas enrichment, and the advantage of oil and gas transmission channel. As a positive tectonic units, with the oil and gas in the process of waterflooding and oil–water interface up and in the nose and anticline formation of remaining oil relative enrichment region[12].

![Figure 3. Remaining oil distribution graph.](image1)

![Figure 4. Reservoir structural diagram.](image2)

**Discussions and Conclusions**

Although there are many methods to describe remaining oil, most methods are based on the qualitative description, and quantitative description of remaining oil research is relatively small and complex. “Remaining oil dynamic data analysis” is a simple method, which uses the production performance data to carry out the quantitative study of the remaining oil. This method has good adaptability to the late high water cut oilfield, with simple and convenient calculation process, and the results is close to the field practice, which has important application value.
References


