Feasibility Study on Reservoir Layered Injection in Sabei Development Zone

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Abstract. Layered water injection is a method to solve the contradiction between layers in the process of oilfield development. It is an important method to achieve effective water injection, maintain the energy of the formation, maintain the long-term stable and high production of the oilfield, and improve the reserves and recovery rate of water drive. In the process of developing by layered water injection method, the common method for determining the distribution of each layer does not consider the distribution of remaining oil in the small layer. Based on the Weng's cycle model and Logistic's law of growth, this paper deduces the quantitative relationship between the production level and the cumulative volume of injected water. According to the distribution rules of remaining reserves in small layers, with the aim of improving the efficiency of water injection sweep and the utilization of remaining oil, a new model for calculating the reasonable injection volume of each layer in the layered injection well based on the distribution of remaining oil was established. The fine numerical simulation method was used to analyze the adaptability of the thickness method, the formation coefficient method and the remaining oil method for layered injection and each stage of the development of the oil field. The remaining oil method is recommended. The research results were applied on site in well group A of the water drive block in the Sabei Development Zone. The water content of the well group decreased by 1.5% and the average daily oil volume increased by 1.2t, indicating a new method of layered injection and the injection volume of each layer the research results of the suitability of the determination method can be used to guide the optimization adjustment of the injection volume of each layer of the injection well in the differentiated layer of the Sabei development.

Key words. Dispensing volume Layered water injection Remaining oil method Water flooding.

1. Introduction
The use of layered water injection technology, by choosing a reasonable amount of small layer injection, can not only effectively alleviate the vertical contradiction, but also maintain a certain formation pressure, increase the water flooding sweep volume, effectively control the rise of water cut, and thus improve the water flooding development effect. The conventional small layer injection methods in the well group mainly include thickness method and formation coefficient method. At present, the injection
intensity of a given block in the Sabei development zone determines the layered injection volume. The essence is that the injection method is based on the effective thickness method. Reflect the requirements of the distribution of remaining oil distribution changes. Therefore, for heterogeneous oilfields with layered injection and production, a new method to determine the distribution of injection in each layer of the layered injection well considering the dynamic changes of the remaining oil distribution between the water injection and oil recovery system, and study its adaptation It is of great significance to improve the efficiency of water injection, achieve fine water injection, increase oilfield output and development level.

2. Theoretical derivation of a new method of layered injection

2.1. Wong Cycle Model

As non-renewable resources, petroleum, natural gas, coal and other fossil energy resources have a limited total amount of resources. As far as the entire process of exploration and development is concerned, its development laws generally conform to the Weng cycle model. In the entire life cycle of oil and gas fields developed by water flooding, there is an internal relationship between the degree of recovery and the amount of water injection. The quantitative relationship between the volume of injected water and the degree of recovery is established based on the Weng cycle model, which provides the possibility of using reservoir engineering methods to describe the remaining oil in the small layer and to determine the reasonable injection volume of the small layer.

2.2. New method of stratified distribution based on remaining oil distribution

2.2.1. Oil and gas field development life cycle characteristics. Before the oil and gas field is put into development, the recovery degree $R$ of recoverable reserves is zero. For waterflood development oilfields, as the volume of injected water $V_{in}$ increases, the recovery degree $R$ of recoverable reserves gradually increases, with $R = R(V_{in})$.

After oil and gas fields are put into waterflood development, the recovery rate of recoverable reserves depends on the rate of change of injected water volume $dR(V_{in})/dV_{in}$ is related to $R(V_{in})$, and $dR(V_{in})/dV_{in}$ decreases as $R(V_{in})$ increases.

When the waterflooding oilfield is abandoned, the volume of injected water reaches the maximum value and the recovery degree of recoverable reserves also reaches the maximum value $b$. At this time, the rate of change of the recovery degree of recoverable reserves reaches a limited extreme value, and $dR(V_{in})/dV_{in} = 0$.

2.2.2. Calculation formula for recoverability of recoverable reserves in water flooding oilfield. The relationship between the recovery degree of recoverable reserves and the volume of injected water satisfies the Weng cycle model. According to the law of Logistic growth, the following differential equations can be established:

$$
\frac{dR}{dV_{in}} = aR(1 - \frac{R}{b})
$$

(1)

Integrate the separation variable for equation (1), and make $c = (b-R_0) / R_0$, simplified to:

$$
R = \frac{b}{1 + ce^{-a(t_a-t_0)}}
$$

(2)

From equation (2), we can see that when $V_{in} \rightarrow \infty$, $R \rightarrow b$, and $b$ is the recovery degree of recoverable reserves when the waterflooding oilfield is developed to the limit. According to the Weng cycle model, all recoverable reserves will be recovered when the oilfield is abandoned, ie $R_\infty = b = 1$. Let $V_{in} = V_{in0}$, $C = Inc$, $A = -a$, simplified to:
\[
\ln(1/R - 1) = C + ADV^-1
\]

In the formula: \( R \) is the recovery degree of recoverable reserves; \( R_0 \) is the recovery degree of recoverable reserves at the initial moment when the oilfield is put into waterflood development; \( b \) is the recovery degree of recoverable reserves when the waterflood oilfield is developed to the limit; \( V_{in0} \) is the injected water volume at the initial moment of the field's waterflooding development; \( a \) is a factor related to reservoir physical properties and well pattern development factors.

**2.2.3. Calculation method of the distribution of small layers based on remaining oil distribution.**

According to the dynamic data of the oil field, make the \( R \) curve \( \ln(1/R - 1) = C + ADV_{in}^{-1} \) and make a linear fit to obtain the parameters \( A \) and \( C \); at the same time, according to the water injection profile of the injection well and the historical data of layered injection, the injection volume and injected water volume of the \( i \) layer are obtained. \( \Delta V_{ini} \). Substitute equation (3) to get the recovery degree \( R_i \) of the \( i \)-layer, and then calculate the remaining recoverable reserves of the \( i \)-layer as \( N_i (1-R_i) \). According to the distribution law of remaining recoverable reserves in small layers, the water injection intensity of remaining oil-rich reservoirs should be strengthened to fundamentally improve the utilization rate of injected water and expand the swept volume. Therefore, the calculation formula of the remaining oil method to determine the injection volume of each layer is:

\[
Q = Q \sum_{i=1}^{n} \frac{N_i(1-R_i)}{N_i(1-R)}
\]

In the formula: \( Q \) injection volume of the whole well, m3; the injection volume of the \( i \)-th layer, m3; \( N_i \) is the geological reserves of the \( i \)-layer, 104 m3; \( n \) is the number of small layers of the water injection well. The method determines the injection volume of each layer of the layered injection well according to the remaining reserves ratio of the small layer, effectively increases the injection volume of the small layer with higher residual reserves, and limits the injection volume of the lower layer with lower residual reserves. The method is called the remaining oil method.

**3. Study on the adaptability of stratified injection method**

**3.1. Model scheme design**

The digital model of the five-point method well pattern was established, and the water content of the well group was divided into several grades, and water injection was started after it was put into production. The oilfield development is divided into 7 stages including water cut 40%, 50%, 60%, 70%, 80%, 90%, 96%, etc., each time the water cut is divided into layers by thickness method, formation coefficient method and remaining oil method Distribution, study the adaptability of various layered distribution methods to different development stages of the oil field.

The formula for calculating the filling volume of each small layer in the layer method of thickness method is:

\[
Q_i = Q \frac{h_i}{\sum_{i=1}^{n} h_i}
\]

The formation coefficient method allocates each small layer, and the calculation formula of the injection volume is:

\[
Q_i = Q \frac{K_i h_i}{\sum_{i=1}^{n} (K_i h_i)}
\]

Where: \( h_i \) is the effective thickness of the \( i \)-layer, m3; \( K_i \) is the effective permeability of the \( i \)-layer.
3.2. Comparison of the effects of different layered injection methods

Using the calculation results of the design plan, draw the relationship curve between the oil increase and the water content of the well group under different layered injection methods, as shown in Figure 1.

![Fig.1 The relationship curve between annual oil increase and water cut by each layered injection method](image)

It can be seen from Figure 1: 1. The oil increase of the remaining oil method of layered injection increases first and then decreases with the increase of water content, and the thickness increase aation factor method is the smallest; 2. When the water content is 50% -80%, The oil-increasnd the formation coefficient method of layered injection of oil increase with the water cut The rate increases and decreases; 2. Under the same water content condition, the remaining oil method has the largest oil increase by layered injection, followed by the thickness method, and the forming effect of the remaining oil method with layered injection is obviously better than the thickness method. 4. When 80% -96%, the remaining oil method is better than the thickness method.

3.3. Analysis on the effect of different stratified injection methods

3.3.1. The essence of the layered injection method of the thickness method is the original reserve method. As the water content of the oil field increases, the interlayer interference increases, the utilization degree of each layer is uneven, the remaining oil distribution changes greatly, and the water flooding effect gradually deteriorates. The essence of the formation coefficient method is the flowability method. This injection method allocates a large amount of water injection to the high permeability and thick oil layer with strong flowability. The injected water quickly breaks along the small layer with strong flowability. The flooding effect gradually gets worse.

3.3.2. When the water cut is low, the recovery is low, and the difference between the original reserves and the remaining reserves is small. Therefore, when the water content is less than 50%, the remaining oil method is slightly better than the thickness method.

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3.3.3. In oilfields in the early stages of medium and high water cut development, the high permeability layer has not only seen water in individual layers, but generally water, and the distribution of remaining oil has changed a lot. However, due to interlayer interference, the middle and low permeability layers have little or no water absorption, so most of the remaining oil in the middle and low permeability layers is still in a contiguous distribution state. At this time, according to the distribution law of remaining recoverable reserves in small layers, increasing the water injection intensity to the remaining oil-rich
reservoirs can improve the utilization rate of injected water and expand the injection water volume. Therefore, when the water content is 50% to 80%, the remaining oil method is better than the thickness method.

3.3.4. Entering the ultra-high water cut development stage oilfield. The water absorption of high permeability layer and middle permeability layer accounts for a larger proportion of the whole well, the low permeability oil layer basically does not absorb water, the remaining oil in low permeability layer is still relatively rich, according to the distribution of remaining recoverable reserves Increase the water injection strength of the remaining oil-rich reservoirs, control the injection of the high and medium permeability layers, and expand the water injection volume of the low permeability layer. When 80% - 96%, the effect of remaining oil layered injection is still better than the thickness method.

4. Application example of remaining oil method layered injection
The well A in block 1 has 10 small layers in the longitudinal direction and is divided into 4 sections. The well was put into production in April 1998. The thickness method was used for layered injection, and the injection effect became worse year by year. In January 2016, the water content of the well group reached 96.6%. For this reason, the remaining oil method was stratified to optimize the volume of each layer of the well.

According to the well group data, the least square method is used to fit the equation (3) to obtain the coefficient A = -7.746 and C = 1.223. According to the injection condition of each layer, the established method is used to determine the new method to calculate the injection amount of each layer. The results are shown in Table 1. The remaining oil method, thickness method and formation coefficient method are shown in Table 2.

| Interval | Pore volume (10⁴m³) | Cumulative water injection (10⁴m³) | Degree of recovery | Remaining reserves (10⁴m³) | Interval injection volume(m³) |
|----------|---------------------|-----------------------------------|-------------------|---------------------------|-------------------------------|
| 1        | 5.28                | 20.06                            | 0.86              | 1.12                      | 40                            |
| 2        | 4.21                | 12.21                            | 0.54              | 3.81                      | 70                            |
| 3        | 5.53                | 17.14                            | 0.65              | 2.64                      | 50                            |
| 4        | 5.79                | 17.95                            | 0.70              | 2.66                      | 50                            |

| Interval | Thickness method | Stratum coefficient method | Remaining oil coefficient method |
|----------|------------------|---------------------------|---------------------------------|
| 1        | 20               | 15                        | 40                              |
| 2        | 90               | 85                        | 70                              |
| 3        | 70               | 60                        | 50                              |
| 4        | 30               | 50                        | 50                              |

On November 6, 2016, the well group implemented the remaining oil method layered injection test. After the deployment, the water content of the well group decreased from 96.6% to 95.1%. On the day, the well group's net oil increase was 438 tons, with an average daily oil increase of 1.2 tons. At the current water cut stage, the new method can make better use of remaining oil and improve the efficiency of water injection.
5. Conclusion

5.1. By deducing the quantitative relationship between the production degree of recoverable reserves and the volume of injected water in a waterflooded oil field, a method for quantitatively describing the remaining oil in a small layer using water injection history is provided.

5.2. Under the same water content condition, the remaining oil method has the best oil increase by layered injection, followed by the thickness method, and the formation factor method is the smallest.

5.3. Through on-site well group tests, the remaining oil method has a layered injection effect with an average single well oil increase of 0.3 tons, which is better than the conventional thickness method to offset the daily oil increase of 0.15 tons.

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