Evaluation of Waterflood Development Effect by Using Recovery Degree of Recoverable Reserves and Cumulative Water Storage Rate

Lijun Huang
The 3rd Oil Production Factory, Daqing Oil Field Company Ltd, Daqing, China

Abstract: For water flooded oilfields, the development effect can be given by analyzing the relationship between the recoverable reserves recovery degree and the cumulative water storage rate and water content. Application of recoverable reserves as the basis for evaluating development effects is more comparable than the extent of geological reserves; The cumulative water storage rate is suitable for evaluating the evaluation unit as a whole since its development. Correctly deriving the relationship between the extent of recoverable reserves recovery and the cumulative water storage and water content are the basic conditions for its application.
In the formula, \( a \) and \( B \) are characteristic curve coefficients of C-type water drive; \( NP \) and \( LP \) are cumulative oil production and liquid production (10^4t).

By transforming formula (1) and deriving the time, we get

\[
N_p = \frac{1}{b} \left[ 1 - \sqrt{a(1-f_w)} \right]
\]  
(2)

Where \( f_w \) is water content (%).

When the ultimate water cut of oil field is 98%, the formula of recoverable reserves is obtained.

\[
N_R = \frac{1}{b} \left[ 1 - \frac{\sqrt{2a}}{10} \right]
\]  
(3)

Where \( N_R \) is recoverable reserves (10^4t).

The relationship between recovery degree of recoverable reserves and water cut can be obtained by dividing (2) (3)

\[
R_{NR} = \frac{1 - \sqrt{a(1-f_w)}}{1 - \sqrt{2a}/10}
\]  
(4)

where \( R_{NR} \) is the recovery degree of recoverable reserves.

Formula (4) is the theoretical evaluation standard of recovery degree and water cut of recoverable reserves.

Water storage rate is an important index to evaluate the development effect of waterflooding oilfield.

The cumulative water storage rate is defined as

\[
E_S = \frac{W_i - W_p}{W_i} = 1 - \frac{W_p}{W_i}
\]  
(5)

Cumulative bet ratio is defined as

\[
Z_S = \frac{W_i}{L_p}
\]  
(6)

Substituting formula (6) into formula (5)

\[
E_S = 1 - \frac{N_p}{Z_S}
\]  
(7)

Substituting formula (1) into formula (7)

\[
E_S = 1 - \frac{a + bN_p - 1}{aZ_S}
\]  
(8)

Substituting formula (2) into formula (8)

\[
E_S = 1 - \frac{a - \sqrt{a(1-f_w)}}{aZ_S}
\]  
(9)

In the formula, \( E_S \) is cumulative water storage rate (%); \( Z_S \) is cumulative injection production ratio.

Equation (9) is the relationship between accumulated water storage rate and water content. The cumulative water storage rate is not only related to water cut, but also to the coefficient of C-type water drive characteristic curve. When other conditions are certain, the cumulative water storage rate increases with the increase of cumulative injection production ratio.

2.2 Selection of cumulative water storage rate for water drive characteristic curve

Based on the mathematical derivation of the other five water drive characteristic curves recommended in the oil and natural gas standard, the relationship between the cumulative water storage rate and the water content is obtained. According to the expressions of six kinds of cumulative water storage rate, the theoretical relation chart is fitted. It can be seen that the C-type water drive characteristic curve is suitable for the prediction and evaluation of the relationship between cumulative water storage rate and water cut. The water drive characteristic curves of type A and type B can't reflect the correct relationship between accumulated water storage and water cut in low water cut stage, while those of type D, Zhang Jiqing and Yu Qitai can't correctly represent the relationship between them in medium high water cut stage.

3 Development effect evaluation of Development Zone G

3.1 Evaluation on recovery degree of recoverable reserves

The values of \( a \), \( b \) and \( R_{NR} \) of 6 blocks in the development zone are obtained by dynamic data fitting, as shown in Table 1.

| Block | \( a \)      | \( b \)      | \( R^2 \) | \( f_w \) | Theory RNR | Actual RNR | \( R \) |
|-------|--------------|--------------|----------|----------|------------|------------|------|
| (A)   | 1.6406334    | 0.0002706    | 0.99977  | 95.25%   | 88.03%     | 91.00%     | 40.56%|
| (B)   | 1.6243483    | 0.0001738    | 0.99981  | 95.63%   | 89.49%     | 90.74%     | 41.33%|
| (C)   | 1.4258130    | 0.0001988    | 0.99959  | 92.26%   | 80.35%     | 92.57%     | 34.12%|
| (D)   | 1.3982903    | 0.0002282    | 0.99964  | 92.64%   | 81.56%     | 92.54%     | 41.59%|
| (E)   | 2.2803966    | 0.0003755    | 0.99972  | 95.51%   | 91.28%     | 91.68%     | 36.33%|
| (F)   | 2.0071406    | 0.0001955    | 0.99988  | 95.91%   | 91.07%     | 91.96%     | 37.39%|

There is little difference in the recovery degree of the current recoverable reserves in six blocks. On the whole, by comparing the theoretical RNR with the actual value of the same block, under the same water cut condition, the recovery degree of the actual recoverable reserves of each block is greater than that of the theoretical recoverable reserves, indicating that the development effect of the six blocks is better. Block C and block d have the best development effect. The actual RNR value exceeds the theoretical value by 10%, and the recovery degree of geological reserves in Block D is the highest in the whole area. Although the actual RNR value of block
3.2 Evaluation with accumulated water storage rate

The trend of change of cumulative water storage rate is restricted by the development system, if the actual water storage rate change trend is basically consistent with the theoretical curve, the water storage rate change will be also relatively stable. That means that the water drive effect is better, and the development system selection is reasonable, and it is conducive to the rational exploitation of oil fields, and the development system should continue to be maintained. It reflects that the water injection condition of the oil field is not stable, which leads to the poor utilization rate of the injection water and the poor effect of water drive. From the change curve of the theoretical water storage rate and the actual water storage rate of each block, it can be seen that the actual water storage rate is basically consistent with the change trend of the theoretical curve, which shows that the water drive effect of 6 blocks is good and the water injection utilization rate is high. In 1980-1990, the cumulative water storage rate of each block decreased faster than that of other blocks in the pure oil area, and the development effect gradually deteriorated, the analysis was due to the "seven-five-year" period of comprehensive pumping, resulting in a decrease in the cumulative water storage rate of the formation;

Secondary encryption wells were put into operation, and there are about 40% of the thickness of the new and old wells at the same time. They played a role in the new and old wells between the water injection structural adjustment. The "steady oil control water" project has been effectively controlled, and the cumulative water storage rate is slowly decreased. During the period 1980-1990, the cumulative water storage rate of Block B decreased faster than that of other blocks in the pure oil area, and the development effect was poor, the analysis was due to the low cumulative injection ratio due to the imbalance of injection. In 1990, the cumulative injection ratio of Block B was 1.14, while the average cumulative injection ratio of the other three blocks in the pure oil area was 1.52. Block A cumulative water storage rate and C block and D block trend is similar, but the theoretical recoverable reserves extraction degree and their difference is quite large, the analysis is that the cumulative injection is relatively high (in the last 10 years has been greater than 1.4) resulting in high water storage rate calculation results, it need to take measures such as sealing and filling holes to achieve efficient water injection. Compared with pure oil area, the initial theoretical accumulation of water storage rate is low, and the actual water storage rate is declining fast, the analysis is mainly due to the intrusion of side water, bottom water, this part of the invasive water for the reservoir is equivalent to the injection of water, but not included in the cumulative injection of water, but increased the yield of water, resulting in low cumulative injection ratio. According to the definition of theoretical cumulative water storage rate, the comprehensive water content is high, the cumulative injection yield is low, and the theoretical cumulative water storage rate is certainly low. And according to the definition of the actual cumulative water storage rate, the cumulative water storage rate must be low if the water production increases.

4 Conclusion

4.1 Correctly deriving the relationship between the extent of recoverable reserves recovery and the cumulative water storage rate and water content are the basic conditions for evaluating the effect of water flooding.

4.2 Type C water flooding characteristic curve is suitable for prediction and evaluation of cumulative water storage rate.

References

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