Study on the variation law of interlayer interference in injection well

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Abstract: In order to solve the problem of flow rate and pressure change in the stratified injection well test process, that is, when the flow rate of one layer is adjusted, the flow rate of other layers also changes. The adjusted layer changes when other layers are adjusted, and the wellhead pressure also changes. Therefore, through the research of this problem, find out the interference coefficient and injection pressure generated by the well transfer of the interfering layer to other layers, so as to realize efficient allocation, and provide ideas and basis for new flow allocation mode.

1. Introduction

The research on the variation law of interlayer interference of injection well is mainly aimed at the problems existing in the testing process, such as the interlayer interference and the great change of pressure and water quantity between layers. It is mainly reflected in the following points: first, when the flow of a certain layer is adjusted, the flow of other layers also changes accordingly. When the adjusted layer is used, the flow of other layers changes again. Second, there is a big error in the comparison between the instantaneous flow detected in the adjustment process and the injection flow at the stable time. Therefore, by carrying out this research, we find out the interference coefficient and injection pressure generated by the nozzle transfer of the interfering layer to other layers, so as to realize the prediction of the flow rate of each layer. Solve the blindness in the deployment process and realize efficient deployment; It provides ideas and basis for new flow allocation methods.

Through the development of multi-parameter interference logging tool and related software, the mathematical model of interlayer interference is established, the law of interlayer interference is analyzed, and the law of interference coefficient is discussed. Through the test analysis, the real meaning of the interference coefficient is found on the basis of the objective factors of interlayer interference, and then the concept of reasonable injection pressure is put forward.

2. The structure and principle of multi-parameter interference logging tool

2.1 The multi-parameter interference logging tool is mainly composed of intelligent switch closure, multi-parameter flow meter, bridge sealing section and other parts. Among them, the intelligent switch closure can change the size of flow passage regularly according to the setting of the program, so as to achieve the purpose of controlling water quantity and realizing inter-layer interference; The internal structure of the multi-parameter flowmeter includes pressure sensors in front of the nozzle, behind the nozzle and flow sensors, which can simultaneously absorb pressure and flow data in front of the nozzle and behind the nozzle in the current layer, thus solving the problem of data acquisition.
2.2 Working principle: the equipment via the cast out of the well layer setting in interference, rely on the built-in control circuit and motor driven flow control switch, close the switch opening width, step by step to control the injection layer closure area, achieve the goal of control of the implanted layer water injection, admission interference and be repeated data, including water injection flow rate, nozzle before and after nozzle pressure, temperature, whole process is controlled by single chip microcomputer.

2.3 Features of the instrument: the instrument can automatically adjust the size of the nozzle at specified time according to the procedure set on the ground, and test the pressure of the nozzle front and back; The intelligent switch closure of the instrument can be adjusted from 1mm to 11mm with a difference of 0.2mm. Detect the change of tip loss; The multi-layer test flowmeter adopts the collecting test method to ensure the accurate enrollment of the flow rate of each layer and the continuous data collection. It can work continuously in the underground.

3. Research on the mathematical model of interlayer interference and modification of interference coefficient

3.1. Mathematical model of interlayer interference

\[ \Delta P_{h_j} = \rho gh \]

Equation of nozzle loss pressure:

\[ P_n = f\left(Q, D\right) \]

Bottom hole pressure of each layer \textit{P}_{wi}:

\[ P_{wi} = P_{\rho, j} + \Delta P_{D, j} - \Delta P_{h_j} + \Delta P_{f, j} \]

On the type, the nozzle pressure loss and flow rate, nozzle size is directly related to water, as long as any one layer flow change, the water injection pressure will change too, when mixing water nozzle size is changed the flow rate, nozzle pressure drop loss has also changed, which creates a wellbore internal pressure, the process of redistribution between each layer which affect the other horizon flux distribution, which creates a water injection system.

3.2. Influence of formation conditions on interlayer interference factors

Formation condition are the essential factors of interlayer interference, also is the fundamental reasons of inside layer interference, because of the existence of the difference between layers, each The vertical depth \( h_j \) is from the surface wellhead to the position of any water nozzle \( j \). The injection fluid flows from the surface to one of the water nozzle with the flow rate

\[ Q = \sum_{j=1}^{m} Q_j \]

\( Q_j \) is the injection volume of layer segments, \( m_j \) is the number of layer segments), and the friction pressure drop of the tubing is:

\[ P_{f, j} = \frac{8 fh_j \rho Q_j^2}{\pi^2 D^5} \]

\( f \) is for the friction coefficient, \( D \) is for the pipe diameter.

Equation of hydrostatic column pressure:

\[ \text{h small layer formation of start-up pressure and permeability is different, in the same water injection pressure with different flow, small layer and have a big hole, a large number of loss of water injection pressure, absorption of water injection, the small permeability of formation can not meet production requirement of injection allocation, and will cause a serious situation of oil well water.} \]

The stratified flow rate of injection well is expressed by well production formula
Due to the difference in permeability and unpredictability, the formula can be regarded as a constant C, and the equation is obtained as follows:

\[ Q = \frac{2\pi kh(P_w - P_e)}{\mu \ln \frac{R_w}{r_w}} \]

Due to the difference in permeability and unpredictability, the formula

\[ Q = C(P_w - P_e) \]

can be regarded as a constant C, and the equation is obtained as follows:

3.3. Definition and Modification of Interlayer Interference Coefficient

Name the disturbance factor as \( n_j \) and define it as:

\[ n_j = \frac{\Delta Q_j}{\Delta Q_m} \]

It can be seen from the above formula that the interference coefficient is related to the change of flow rate and pressure to some extent. \( C_i \) and \( C_j \) are also constants, so theoretically, the interference coefficient is a relative value.

Correction of interference coefficient:

\[ n_i = \frac{Q_i}{Q_j} = \frac{C_i(P_{w_i} - P_e)}{C_j(P_{w_j} - P_e)} \]

By modifying the interference coefficient and using \( Q_i, Q_j \) as the injection flow rate, a reasonable injection pressure point can be found to achieve efficient allocation.

4. The Stability Time of the Test is Related to the Water Absorption Capacity of the Formation. The better the water absorption capacity is, the shorter the stability time will be.

According to the test of multi-parameter interference logging tool in the four layers of stratified well A1, the flow line after the downhole transfer nozzle is different in terms of the nozzle size and water absorption capacity, and the flow line stability time is different. For example, layer B1 is a non-interfering layer due to its small injection amount and the injection pressure is always stable above the formation starting pressure. The injection pressure tends to be stable after 24 minutes, and the injection water quantity is on the rise, with the difference of water quantity being 4.1m³/d. The water tip in the layer B2 is 5.8mm, which is relatively large and belongs to the general interference layer. The water injection pressure tends to be stable within 20 minutes, and the water injection volume shows a downward trend, with water volume of 1.1m³/d. The nozzle size of the layer B3 is 2.4mm, and the nozzle size is small. Due to its good water absorption, the flow rate changes significantly and it is a strong interference layer. After 13 minutes, the water injection pressure tends to be stable, and the water injection volume shows a downward trend, with water volume of 1.8m³/d. The nozzle in the layer B4 is 4.0mm, belonging to the medium interference layer. The injection pressure tends to be stable after 18 minutes, and the injection water volume shows a downward trend, with a water volume of 2.1m³/d. It can be seen from the test results that the stability time is basically maintained between 20 and 30 minutes, and the test data are shown in the table below.
Table 1. Water flow change and stabilization schedule after interference test in Well A1

| Layer Segment | type               | Injection allocation (m³/d) | Water nozzle (mm) | Water changes | Stabilization time (min) |
|---------------|--------------------|-----------------------------|-------------------|--------------|-------------------------|
|               |                    |                             |                   | Early (m³/d) | Stability (m³/d)        | Difference (m³/d) | Total Stabilization time (min) |
| B1            | No interference    | 10                          | 12.0              | 2.5          | 6.6                     | 4.1                | 24                             |
| B2            | General interference| 40                          | 5.8               | 25.2         | 24.1                    | 1.1                | 20                             |
| B3            | Strong interference| 30                          | 2.4               | 40.2         | 38                      | 2.2                | 13                             |
| B4            | Medium interference| 70                          | 4.0               | 55.2         | 53.1                    | 2.1                | 18                             |
| Total         |                    | 150                         |                   | 123.1        | 121.8                   |                    |                                |

5. The variation law of interlayer interference is discussed

5.1 Determination of interference layer and selection of test method

Through the analysis of the measured data of 8 Wells, it is found that some factors affecting the interference in the testing process are related to formation pressure, water absorption and geological factors. Namely, the greater the interference, the greater the pressure and water absorption of the target layer; The less the interference, the less the pressure and water absorption of the target layer. The well with greater influence of interference test indicates that the choice of interference layer is correct, while the well with less variation of interference test indicates that the choice of interference layer is wrong. In this way, the choice of the interference layer is important. At the same time, there are some differences in the intensity of interference.

According to the physical meaning of the interference coefficient, low formation pressure of injection allocation, we should choose the big flow formation as a interference layer, in this way, the water nozzle switch process will cause the change of wellbore pressure is obvious, but if you choose to high pressure injection allocation as the interference layer, caused by the change of the borehole water injection pressure is limited, so will cause the phenomenon of interference is not obvious.

Firstly, the interference layer should be optimized according to the geological characteristics of different underground layers. For different Wells, we can adopt different interference test methods, active interference test and passive interference test. Need test on some production Wells, active interference test, and can be used by ground control pressure changes for testing purposes, and if the need for the analysis of the geological well, need long time stability test, using passive interference test, by instrument automatic deployment of downhole interference layer water nozzle size to complete the test, because this test is performed by instrument, so it is called passive interference test. The purpose of both active and passive interference tests is not only to adjust the size of the nozzle, but also to obtain continuous data of variation, thus providing objective data for geological analysis and measure evaluation.

5.2 Classification principles and judgment conditions of interference factors

According to the test and interference coefficient results, the interference interval can be divided into the following categories: for homogeneous reservoirs and non-interference layer, the average interference coefficient interval should be between 0–0.05, the formation coefficient is small, the injection water quantity is unlimited, the nozzle is generally greater than 8.0mm, and the flow adjustment fluctuation range can be 0–2 m³/d. The interval of average interference coefficient of general interference layer should be between 0.05 and 0.2. The formation coefficient is relatively small, the water injection amount is unlimited, the nozzle is generally greater than 5.0mm, and the fluctuation range of flow adjustment can be between 2 and 5 m³/d. The interval of average interference coefficient of the medium interference layer should be between 0.2 and 0.5. The formation coefficient is relatively large, the water injection volume is high, the nozzle is generally less than 5.0mm, and the fluctuation range of flow adjustment can be between 5 and 10 m³/d. The average interference coefficient of the strongly disturbed layer should be above 0.5, the formation coefficient is large, the injection water
quantity is high, the nozzle is generally less than 3.0mm, and the flow adjustment fluctuation range can be above 10m³/d.

5.3. Study on the interference coefficient of different layers and segments
According to different layers and interval, we selected 20 Wells to conduct interlayer interference test with multi-parameter interference logging tool. Through setting interference multiparameter logging tool on the ground of adjustable switch action program, and then separately into the multi-parameter logging tool interference within the layered, in a set time, instrument switch began to change, and continuous monitoring of stratified flow pressure change, collecting test data needed, after the test, layered pressure flow data, calculate interference coefficient, specific data statistics as follows.

Table 2. Statistical table of interference coefficient of different layers

| formation          | number of Wells | classification | The layer numbers | Interference coefficient range | Interference coefficient (Average Value) |
|--------------------|-----------------|----------------|-------------------|-------------------------------|------------------------------------------|
| Basic well pattern | 3               | Strong interference layer | 2 | > 0.5 | 0.891 |
|                    |                 | Medium interference layer | 4 | 0.2-0.5 | 0.328 |
|                    |                 | General interference layer | 3 | 0.05-0.2 | 0.132 |
|                    |                 | No interference layer | 0 | 0-0.05 | 0.000 |
| Primary encryption | 4               | Strong interference layer | 3 | > 0.5 | 0.521 |
|                    |                 | Medium interference layer | 8 | 0.2-0.5 | 0.226 |
|                    |                 | General interference layer | 4 | 0.05-0.2 | 0.071 |
|                    |                 | No interference layer | 0 | 0-0.05 | 0.000 |
| Secondary encryption | 8          | Strong interference layer | 3 | > 0.5 | 0.613 |
|                    |                 | Medium interference layer | 10 | 0.2-0.5 | 0.411 |
|                    |                 | General interference layer | 11 | 0.05-0.2 | 0.08 |
|                    |                 | No interference layer | 2 | 0-0.05 | 0.025 |
| Third encryption   | 5               | Strong interference layer | 2 | > 0.5 | 0.683 |
|                    |                 | Medium interference layer | 5 | 0.2-0.5 | 0.383 |
|                    |                 | General interference layer | 5 | 0.05-0.2 | 0.162 |
|                    |                 | No interference layer | 3 | 0-0.05 | 0.034 |
| Total              | 20              |                | 65 |            |                                |

Interference by the different formations and different interval coefficient statistics shows that because of the influence of geological factors causing interference phenomena exist in the interlayer, layer, makes the interference coefficient value even under the same classification change is big, do not have constancy and universality, specific test data can be reference to the well test curve.

5.4. Research on active interference test methods
Firstly, after the instrument is lowered to the injection zone, the injection pressure is increased and controlled at the wellhead, and the test time to be waited is calculated according to different depths and wellhead flow.

Secondly, from high pressure to low pressure control in the test process flow on the ground, each well testing, down from the highest pressure point for each steps reduce pressure points, each point of the test time is from 10 minutes to 30 minutes, because this paragraph of time the decompression process, the formation of the volume expansion factor will have interference, wellhead flow stability, means that under certain pressure, the volume expansion factor of interference have been eliminated, can continue to reduce a pressure point test.

Finally, take the same method to test the continuous pressure and flow data of 5 or 6 steps, and then test the pressure recovery curve of each layer for more than 30 minutes after shut-in. During this
period, the flow rate of the downhole flowmeter will still be available due to the wellbore storage, so that the actual condition of each layer can be observed, whether there are cracks or large orifices.

5.5. Use the interference coefficient to determine the reasonable injection pressure and guide the stratification test of the injection well

Through the analysis of field test application and test results, we have obtained how to use the test results of the multi-parameter interference logging tool to select the method of reasonable injection pressure of water injection, so as to guide the efficient deployment of the technology. The methods are as follows.

5.5.1. Select representative Wells as fixed-point Wells, use multi-parameter interference logging tool for fixed-point well testing, determine formation geological characteristics, calculate interference coefficient, and then select reasonable injection pressure.

5.5.2. When the injection well test and deployment with the same layer property is carried out, the current injection pressure of the injection well can be calculated by using the conversion relation between the interference coefficient measured by the fixed-point well and the reasonable injection pressure, and the reasonable expected water volume or the accurate calculation of the nozzle diameter can be made.

5.5.3. When the tester performs flow regulation, first adjust the wellhead pressure to the reasonable injection pressure requirements, and then adjust the water nozzle diameter of the formation with high injection pressure to meet the injection requirements within a small water nozzle range. According to the interference coefficient measured by the fixed-point well and the injection pressure and water volume, the nozzle diameter to be allocated can be accurately calculated in other layers to avoid the problem of repeated measurement and adjustment in the original method.

6. Conclusion

6.1. The interference coefficient is not constant and universal. The complexity of interference is affected by the crack opening pressure and the closure pressure. The calculation of interference coefficient can only be realized when it is higher than the fracture opening pressure. However, the interference coefficient lower than the closure pressure is distorted.

6.2. The active interference test method can be used to determine the reasonable injection pressure and nozzle allocation size, so as to improve the accuracy of test data and measurement and adjustment efficiency

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