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Research on the Reasonable Injection-Production Ratio of Z Block

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Abstract: Reasonable injection-production ratio is very important for stable production capacity of oil field. But reasonable injection-production ratio is often difficult to determine. This paper applies a method according to the relationship between injection-production ratio and water-oil ratio and the method combining material balance principle and Logistic cycle theory to determine the reasonable injection-production ratio. This method considers the effect of inefficient water injection and other factors, so it is very reliable. Through this forecast method, we can get the reasonable injection-production ratio of Z block. We can planning and design water injection of an oilfield through it, so this method has a strong guiding significance.

Key words: *Reasonable injection-production ratio; Material balance principle; Logistic cycle theory; Z block*

I. INTRODUCTION

Reasonable injection-production ratio is an important guarantee for oilfields to maintain the reservoir pressure, not to make water content rising too fast, to have a high production capacity and achieve relatively higher recovery. For a given well pattern, there are many factors which can influence the injection-production ratio, including the reservoir pressure, fluid production and water cut. The prediction methods of injection-production ratio commonly used include the method according to the relationship between injection-production ratio and water-oil ratio, material balance method and artificial neural network method. Artificial neural network method is a cassette model and its results are difficult to interpret. Therefore, this paper applies a method according to the relationship between injection-production ratio and water-oil ratio and the method combining material balance principle and Logistic cycle theory to determine the reasonable injection-production ratio.

1 The Material Balance Principle and Logistic Cycle Theory

Research ideas of this method is: firstly, use material balance principle to determine the relationship between rate of pressure recovery and underground liquid volume difference between injection and production, then determine the relationship between rate of pressure recovery and the injection-production ratio and water content according to the relationship between annual injection-production fluid volume and the injection-production ratio.

1.1 Applying Material Balance Principle to Determine Rate of Pressure Recovery

Under the condition of artificial water injection, the following equation can be available according to the principle of material balance:

$$\frac{N_p B_o}{\rho_o} = \frac{N B_{oi} C_t (p_i - p)}{\rho_o} - (W_i - W_p) B_w \tag{1-1}$$

where N represents oil initially in place, 10^4t; N_p represents cumulative oil production, 10^4t; P_i represents initial reservoir pressure, MPa; P represents current reservoir pressure, MPa; ρ_o represents density of stock tank oil, kg/m^3; C_t represents the total compressibility of reservoir, 1/MPa; B_{oi} represents the original oil volume factor; B_o represents current oil volume factor; B_w represents formation water volume factor; W_i represents cumulative water injection, 10^4m^3; W_p represents cumulative water production, 10^4m^3.

When the change of reservoir pressure is kept within an allowable range, the formation oil volume factor can be regarded as a constant, finally rate of pressure recovery per year can be obtained:

$$\frac{dp}{dt} = k Q_i \left[1 - \left(\frac{Q_o B_{oi}}{\rho_o} + Q_w B_w \right) \Big/ Q_i B_w \right] \tag{1-2}$$

Let $$\frac{dp}{dt} = k \Delta Q_{If}$$

where k is a constant concerned with oil initially in place and the properties of rocks and underground fluid;

ΔQ_{If} represents underground liquid volume difference between injection and production per year, 10^4t/a.
Considering the effect of inefficient water injection and other factors, the relationship between underground injection-production liquid volume difference per year and rate of pressure recovery per year could be expressed as follows:

$$\frac{\mathrm{d}p}{\mathrm{d}t} = k\Delta Q_{\mathrm{If}} - b \tag{1-3}$$

where b is a variable concerned with the effect of invalid water injection on rate of pressure recover, MPa/a.
According to the definition of injection-production ratio, the relationship between injection-production liquid volume difference and annual contribution can be obtained:

$$\Delta Q_{\mathrm{If}} = \left(1 - \frac{1}{IPR}\right)Q_{\mathrm{i}} \tag{1-4}$$

1.2 Applying Logistic Cycle Theory to Determine the Relationship between Rate of Pressure Recovery and Injection-Production Ratio

The mathematical model concerning composite water cut of blocks, cumulative water consumption and cumulative oil-water ratio was established , based on the Logistic cycle theory, after determining the relationship between rate of pressure recovery of blocks and injection-production ratio、water injection rate.
The mathematical model of Logistic cycle is:

$$X = \frac{D}{1 + Ae^{-Bt}} \tag{1-5}$$

where X represents system; t represents development process or time of the system; D is empirical constant of life processes; A and B are both fitting coefficients.
Cumulative water consumption refers to the amount of water required to produce a ton of oil, which can be expressed by the following equation:

$$H_{\mathrm{cum}} = \frac{W_{\mathrm{i}}}{N_{\mathrm{p}}}$$

Cumulative water-oil ratio refers to the amount of water produced when a ton of oil is produced, which can be expressed by the following equation:

$$WOR_{\mathrm{cum}} = \frac{W_{\mathrm{p}}}{N_{\mathrm{p}}}$$

As for water flood fields, the cumulative water consumption and the cumulative water-oil ratio increased, and composite water cut rose with development time going by, and $\lim_{t\to\infty} f_{\mathrm{w}}=f_{\mathrm{wlim}}$. Logistic cycle model can be used to establish the quantitative relationship between composite water content and cumulative water consumption, and cumulative water-oil ratio:

$$f_{\mathrm{w}} = \frac{f_{\mathrm{wlim}}}{1 + A_1 e^{(-B_1 H_{\mathrm{cum}})}}$$

$$f_{\mathrm{w}} = \frac{f_{\mathrm{wlim}}}{1 + A_2 e^{(-B_2 WOR_{\mathrm{cum}})}}$$

To take natural logarithm on both sides of the above two equations, then

$$\ln\left(f_{\mathrm{wlim}} / f_{\mathrm{w}} - 1\right) = \ln A_1 - B_1 H_{\mathrm{cum}} \tag{1-6}$$

$$\ln\left(f_{\mathrm{wlim}} / f_{\mathrm{w}} - 1\right) = \ln A_2 - B_2 WOR_{\mathrm{cum}} \tag{1-7}$$

where f_{w} is the composite water cut of the block or oilfield, decimal; f_{wlim} is the water cut limit of the block or oilfield, the general value is 0.98; W_{i}, W_{p} are cumulative water injection and cumulative water production of the block or oilfield respectively, $10^4\mathrm{m}^3$; N_{p} represents cumulative oil production of the block or oilfield, 10^4t; WOR_{cum} represents cumulative water consumption of the block or oilfield, 10^4t; A_1、B_1、A_2、B_2 are fitting coefficients.

For the same oil field or block, the equation (1-6) is equal to the equation (1-7), then

$$H_{\mathrm{cum}} = \frac{\ln A_1 - \ln A_2}{B_1} + \frac{B_2}{B_1} WOR_{\mathrm{cum}} \tag{1-8}$$

According to the definition of the cumulative water consumption and the cumulative water-oil ratio, the following equation could be obtained:

$$W_{\mathrm{i}} = \frac{\ln A_1 - \ln A_2}{B_1} N_{\mathrm{p}} + \frac{B_2}{B_1} W_{\mathrm{p}} \tag{1-9}$$

Taking differential with respect to time on both sides of the equation (1-9), the following equation could be obtained:

$$\frac{\mathrm{d}W_{\mathrm{i}}}{\mathrm{d}t} = \frac{\ln A_1 - \ln A_2}{B_1} \frac{\mathrm{d}N_{\mathrm{p}}}{\mathrm{d}t} + \frac{B_2}{B_1} \frac{\mathrm{d}W_{\mathrm{p}}}{\mathrm{d}t} \tag{1-10}$$

Bringing $Q_i = \frac{dW_i}{dt}$, $Q_o = \frac{dN_p}{dt}$ and $Q_w = \frac{dW_p}{dt}$ into the equation (1-10), the following equation could be obtained:

$$Q_i = \frac{\ln A_1 - \ln A_2}{B_1} Q_o + \frac{B_2}{B_1} Q_w \quad (1\text{-}11)$$

Owing to $Q_w = \frac{f_w}{1 - f_w} Q_o$, it was brought into the equation (1-11), we can get after reorganizing:

$$Q_i = \left(\frac{\ln A_1 - \ln A_2}{B_1} + \frac{B_2}{B_1} \frac{f_w}{1 - f_w} \right) Q_o \quad (1\text{-}12)$$

where t represents time, a; Q_i, Q_w are annual contribution and annual water production rate of the unit or block respectively, $10^4 m^3$; Q_o represents yearly rate-oil production of the unit or block, $10^4 t$.
The equation coefficients ($\ln A_1$, B_1, $\ln A_2$, B_2) could be calculated by linear regression of $\ln(0.98/f_w - 1)$ to H_{cum} and WOR_{cum} in the equation (1-6) and the equation (1-7). The equation (1-12) is the quantitative relationship between annual yield and annual contribution in different water cut period of the oilfield or block.
The relationship between rate of pressure recovery and yearly rate-oil production can be obtained according to the combination of the equation (1-1), (1-3) and (1-12):

$$\frac{dp}{dt} = k \left(1 - \frac{1}{IPR}\right) \left(\frac{\ln A_1 - \ln A_2}{B_1} + \frac{B_2}{B_1} \frac{f_w}{1 - f_w} \right) Q_o - b \quad (1\text{-}13)$$

The equation (1-13) indicates the relationship between different rates of pressure recovery and the optimal injection-production ratio.

II. REASONABLE INJECTION-PRODUCTION RATIO OF Z BLOCK

In 2014, yearly rate-oil production of Z block was $2.2606 \times 10^4 t/a$, water content was 46.52%. By fitting the actual dynamic data of water drive in Z block, the relationship between injection-production ratio of water flooding, water cut and rate of pressure recovery in Z block can be obtained:

$$\frac{dp}{dt} = 0.1696 \left(1 - \frac{1}{IPR}\right) \left(2.4413 + 4.6212 \frac{f_w}{1 - f_w} \right) Q_o - 0.6825 \quad (1\text{-}14)$$

Relation curve of injection-production ratio and rate of pressure recovery was shown by Fig.1. As shown in Fig.1, rate of pressure recovery increases with increasing injection-production ratio. The reservoir pressure of Z block was 13.3MPa in 2014. Reservoir pressure corresponding to different injection-production ratios can be calculated according to different rates of pressure recovery, as shown in table 1.

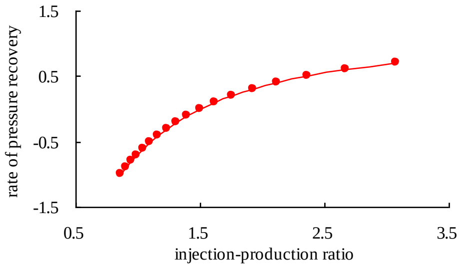

Fig.1 Relationship between injection-production ratio and rate of pressure recovery in Z block

Table1 Relationship between injection-production ratio and reservoir pressure in Z block

injection-production ratio	0.9	1.0	1.2	1.5	1.9	2.7
reservoir pressure(MPa)	12.4	12.7	13.0	13.3	13.6	13.9

Current reservoir pressure in 2014 is 13.3MPa, as to maintain the pressure of production, injection-production ratio is 1.5 when the rate of pressure recovery of Z block is 0. So the reasonable injection-production ratio of Z block is 1.5.

III. CONCLUSION

1) This paper proposes a reliable method to determine the reasonable injection-production ratio applying combining material balance principle and Logistic cycle theory.
2) Applying this new forecast method, the reasonable injection-production ratio of Z block is 1.5.

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