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Orginal article

A new approach of proration-injection allocation for water-flooding mature oilfields

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A B S T R A C T

This paper presents a new method of injection-production allocation estimation for water-flooding mature oilfields. The suggested approach is based on logistic growth rate functions and several type-curve matching methods. Using the relationship between these equations, oil production and water injection rate as well as injection-production ratio can be easily forecasted. The calculation procedure developed and outlined in this paper requires very few production data and is easily implemented. Furthermore, an oilfield case has been analyzed. The synthetic and field cases validate the calculation procedure, so it can be accurately used in forecasting production data, and it is important to optimize the whole injection-production system.

1. Introduction

Mature oilfields are very important for meeting oil demand because they produce about 70% of the total world oil production. One of the most important problems associated with mature oilfields is high water cut, which can significantly decrease oil production rates. There is a need to apply new alternative technologies or approaches to extend the life of these oilfields.

For water-flooding oilfields, determining the reasonable injection-production allocation is the basis work during the oilfield development process, which has direct impact on well performance. Currently used methods are material balance method [1–3], water-flooding curve method [4–6], multiple regression method [7–9] and so on. This paper presents a new method for empirically forecasting production, water injection rate and injection-production ratio based on the logistic growth model and several type-curve matching methods.

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2. Methodology

The specific proration-injection allocation of oilfields is divided into three steps: to determine oil production; to predict water injection rate; to calculate injection-production ratio.

2.1. Determination of production

Logistic growth curves are a family of mathematical models used to forecast growth in numerous applications. They have come to be used in different fields for numerous things. Studies have shown that the logistic model equation also applies to researches on oilfield cumulative production. The form of the logistic equation [12] is as follows:

$$N_P = \frac{a}{1 + be^{-ct}} \quad (1)$$

where a, b and c are constants and greater than 0, which are obtained by fitting the production data. It can be inferred from equation (1) that when t is big enough, N_P equals to the recoverable reserve (N_R) of the oilfield, so constant $a = N_R$ and equation (1) can be written as:

$$N_P = \frac{N_R}{1 + be^{-ct}} \quad (2)$$

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The logistic growth model is as the name implies a growth equation. In this case the growth is cumulative oil production [11]. The derivative with respect to time can be taken to obtain the rate form:

$$Q_O = \frac{dN_P}{dt} = \frac{bcN_R e^{-ct}}{(1+be^{-ct})^2} \tag{3}$$

Equation (4) can be got by equation (3) divided by (2) as follows:

$$\frac{Q_O}{N_P} = \frac{bce^{-ct}}{1+be^{-ct}} \tag{4}$$

The following can be obtained by combining equation (2) with equation (4):

$$\frac{Q_O}{N_P} = c - \frac{c}{N_R}N_P \tag{5}$$

It can be seen in equation (5) that a straight line can be obtained by plotting Q_O/N_P vs. N_P in a rectangular coordinate system. Parameter c can be determined by the intercept of the straight line, and parameter N_R can be determined by the slope.

Moreover, equation (2) can be transformed into the following:

$$\frac{N_R}{N_P} = 1 + be^{-ct} \tag{6}$$

For equation (6), setting the intercept = 1, parameter b can be obtained by plotting N_R/N_P vs. e^{-ct} using the production data in a rectangular coordinate system. Substituting N_R, b and c into equation (3), equation (7) can be used to forecast the annual oil production:

$$Q_O = \frac{bcN_R e^{-ct}}{(1+be^{-ct})^2} \tag{7}$$

2.2. Determination of water injection rate

For water-flooding oilfields, the relationship between cumulative water injection and cumulative oil production is as follows [10]:

$$\ln(w_i) = A + BN_P \tag{8}$$

A and B can be obtained by the regressions of the cumulative water injection and cumulative oil production. And another form of equation (8) is as follows:

$$W_i = e^A e^{BN_P} \tag{9}$$

Substituting equation (2) into equation (9) and taking the derivative with respect to t, the following equation can be got to predict the annual water injection.

$$Q_{inj} = E\frac{e^{-ct}}{(1+be^{-ct})^2} e^{\left(\frac{BN_R}{1+be^{-ct}}\right)} \tag{10}$$

where, $E = e^A bcBN_R$

2.3. Determination of injection-production ratio

For water-flooding oilfields, the relationship between cumulative water production and cumulative oil production is as follows [12]:

$$\ln(W_P) = \alpha + \beta N_P \tag{11}$$

Also, equation (11) can be rewritten as:

$$W_P = e^{\alpha} e^{\beta N_P} \tag{12}$$

Substituting equation (1) into equation (12), the relationship between cumulative water production and the reservoir development time can be obtained as follows:

$$W_P = e^{\alpha} e^{\beta N_R/\left(1+be^{-ct}\right)} \tag{13}$$

The derivative of the cumulative water production W_P is the annual water production Q_W. The annual water production $Q_W = dW_p/dt$ is:

$$Q_W = F\frac{e^{-ct} e^{\beta N_R/\left(1+be^{-ct}\right)}}{(1+be^{-ct})^2} \tag{14}$$

where, $F = bc\beta N_R e^{\alpha}$

According to the definition of injection-production ratio:

$$IPR = \frac{Q_{inj}B_W}{Q_O\frac{B_o}{\gamma_o} + Q_W B_W} \tag{15}$$

Substituting equation (7), (10) and (14) into equation (15), the annual injection-production ratio in the year of t can be got as follows:

$$IPR = \frac{Ee^{BN_R/\left(1+be^{-ct}\right)}}{H + Fe^{\beta N_R/\left(1+be^{-ct}\right)}} \tag{16}$$

where, $H = B_o bcN_R/\gamma_o$

According to the definition of cumulative injection-production ratio:

$$R_z = \frac{W_i B_W}{N_P\frac{B_o}{\gamma_o} + W_P} \tag{17}$$

Equation (2), (9) and (12) are substituted into equation (17), equation (18) can get obtained:

$$R_z = \frac{B_W e^A e^{BN_R/\left(1+be^{-ct}\right)}}{\frac{N_R}{1+be^{-ct}}\frac{B_o}{\gamma_o} + B_W e^{\alpha} e^{\beta N_R/\left(1+be^{-ct}\right)}} \tag{18}$$

Finally, based on equation (16) and (18), the annual injection-production ratio and the cumulative injection-production ratio can be simulated.

3. A case study

XM reservoir is a typical low permeability lithologic fault block oil reservoir. Its M2 Block covers a development area of 7.16 km^2, with reserves of 351 × 10^4 t, a mean permeability of 6.6 × 10^{-3} μm^2, and a mean porosity of 15.2%. In addition, the average formation temperature is 70 °C, the original saturation pressure is 3.13 MPa, the density of crude oil is 0.82 g/cm^3, the viscosity is 8.7 mPa.s and the formation volume factor is 1.056. With the water-flooding development since 1990, the reservoir has gone through four stages: the incremental production stage (1990–1993), the basic well pattern development stage (1994–1996), the stable production stage (1997–2001) and the depletion stage (2001 to present). The well pattern was adjusted in 1998, 2001 and 2007, respectively. At present, the five-spot