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A New Method to Determine the Productivity Equation Coefficient of Low Permeability Gas Reservoir

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A New Method to Determine the Productivity Equation Coefficient of Low Permeability Gas Reservoir

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Abstract. Stress sensitivity exists in the development of low permeability gas reservoir, which leads to the large difference between the productivity of gas well in the middle-late stage and the initial stage. Gas field production usually uses empirical formula to calculate productivity equation coefficient by known well test data or static pressure. However, in actual production, due to economic reasons, well testing cannot be carried out frequently, or interrupted production to obtain the static pressure, so the actual productivity of gas Wells cannot be obtained quickly. This paper combined the material balance equation with binomial productivity equation, and the coefficient of productivity equation is obtained by using the fitting analysis of single well production history data. This method overcomes the dependence of traditional method on formation pressure, and the productivity equation which calculated by this method can reflect the influence of stress sensitivity on gas well productivity, it provides a new method for productivity analysis of low-permeability gas reservoirs.

1. Introduction
The evaluation of gas well productivity is an important work to determine the reasonable gas wells production and evaluate the production capacity of gas fields [1]. The reliability of the evaluation results is directly related to the safety and stable production of gas fields, and the calibration of gas well productivity runs through the whole life cycle of gas field development. At present, the common production capacity calibration method in Dagang oilfield is to calculate the open flow capacity by binomial production capacity equation [2]. Usually, there are three ways to obtain the productivity equation coefficient: one is to use the productivity well test data to analyse and calculate [3]; the other method is to use the theoretical formula to calculate; the third is to estimate it according to the empirical statistical relationship [4]. These three methods all require reliable pressure test data.

There are a large number of low-permeability gas reservoirs in Dagang oilfield, which are deeply buried, high temperature and high pressure. All these factors lead to high pressure measurement risk, and the pressure measurement data is insufficient to calculate the productivity equation. Even if the productivity test is carried out at the initial stage, the productivity in the production process is constantly changing due to the stress sensitivity in the low-permeability gas reservoir, but it is impossible to frequently interrupt the production to measure the pressure in the gas field production. So how to accurately evaluate the productivity in the production process of the low-permeability gas reservoir is an urgent problem to be solved.

In view of the limitation of conventional productivity evaluation method subject to pressure, this paper based on binomial productivity equation and the material balance equation, finally obtained the bottom hole flow pressure expression with parameters contain productivity coefficient, single well control dynamic reserves, and water invasion intensity. The actual bottom-hole flow pressure can be calculated by using the wellhead pressure and output of productive gas wells. By constantly adjusting the productivity coefficient, single well control dynamic reserves, water invasion intensity and other parameters, the error between the calculated bottom-hole flow pressure and the actual bottom-hole flow pressure is minimized, and the flow pressure curve of gas Wells is fitting optimized, then we can obtain the productivity equation coefficient. The biggest advantage of this method is that it does not need to measure pressure, and the parameters such as dynamic reserves and production capacity equation can be determined by fitting according to the production dynamic data.

2. Establishment of Model

2.1. Gas reservoir material balance equation

Most low permeability gas reservoirs in Dagang oilfield have edge water. The expression of material balance equation of water drive gas reservoirs can be expressed as a function of cumulative gas production and water invasion intensity [5]:

$$\frac{P}{Z} = \frac{P_i}{Z_i}\left[\frac{1-\frac{G_p}{G}}{1-\left(\frac{G_p}{G}\right)^R}\right] \qquad (1)$$

The meaning of letters in a formula:

P—formation pressure，MPa;

P_i—original reservoir pressure，MPa;

z—Gas phase deviation factor corresponding to formation pressure P;

z_i—Gas phase deviation factor corresponding to formation pressure P_i;

G_p—Cumulative gas reservoir production，$10^8 m^3$;

G—Gas reservoir dynamic reserves，$10^8 m^3$;

R—Water invasion intensity of gas reservoir，Strong water invasion of gas reservoir R 1 ～ 4，Weak water invasion of gas reservoir R＞4.

Then, the formation expression of the gas reservoir pressure is deformed from equation (1), and the following equation can be obtained:

$$P = \frac{P_i Z}{Z_i}\left[\frac{1-\frac{G_p}{G}}{1-\left(\frac{G_p}{G}\right)^R}\right] \qquad (2)$$

2.2. Binomial productivity equation

The common method to calculate the gas reservoir productivity in Dagang oilfield is the binomial productivity formula [6]

$$P^2 - P_{wf}^2 = Aq + Bq^2 \qquad (3)$$

The meaning of letters in a formula:

P—formation pressure，MPa;

P_{wf}—flowing bottom hole pressure，MPa;

q—gas-well production，m^3。

2.3. Establishment of flow pressure calculation model

Substitute equation (2) into equation (3), then flowing bottom hole pressure in binomial productivity equation can express by the available parameters of gas well production q, production equation coefficient A B, dynamic reserves G and water invasion intensity R:

$$P_{wf}^* = \sqrt[2]{\left[\frac{P_i Z}{Z_i}\left[\frac{1-\frac{G_p}{G}}{1-\left(\frac{G_p}{G}\right)^R}\right]\right]^2} - Aq - Bq^2 \qquad (4)$$

3. Solution of model

First, in the flowing bottom hole pressure calculation model (4), the productivity equation coefficient A B, water invasion intensity R and single well control reserves G are the parameters which should be calculate. According to the experience, the values were assigned in the parameter range to calculate the flowing bottom-hole pressure corresponding to different production rates of a single well.

The value of coefficient A in productivity equation ranges from 0 to 500, the value of coefficient B is range from 0 to 10. The value of single well controlled reserves G is range from cumulative production of a single well from 20 times of cumulative production, and the value of water invasion intensity R is range from 0 to 10.

Second, Judge the calculated flow pressure is reasonable. We should compare the calculated flow pressure value with actual flow pressure. If there is a measured flow pressure value, it is compared with the measured value. If not, the wellbore flow model [7] can be used to calculate the actual bottom-hole flow pressure by using the wellhead oil pressure, actual gas production and water yield of the producing gas well. The closer the calculated flow pressure value is to the actual flow pressure value, the two have the smallest error, and the value of equation (5) is the smallest, which indicate that the values of A, B, G and R are reasonable, then the productivity equation coefficient A and B can be obtained.

$$I_P = min \sum_{i=1}^{n}\left(P_{wf} - P_{wf}^*\right)^2 \qquad (5)$$

The meaning of letters in the formula:

P_{wf}^*- Calculated flowing bottom-hole pressure

P_{wf}-Actual flowing bottom-hole pressure

I_p- The target fitting function

Formula (5) adopts automatic fitting method; essentially it is a parameter identification problem, that is, seek the optimal parameters to fit the theoretical value and the measured value, so as to minimize the objective function. The specific calculation route is shown in figure 1.
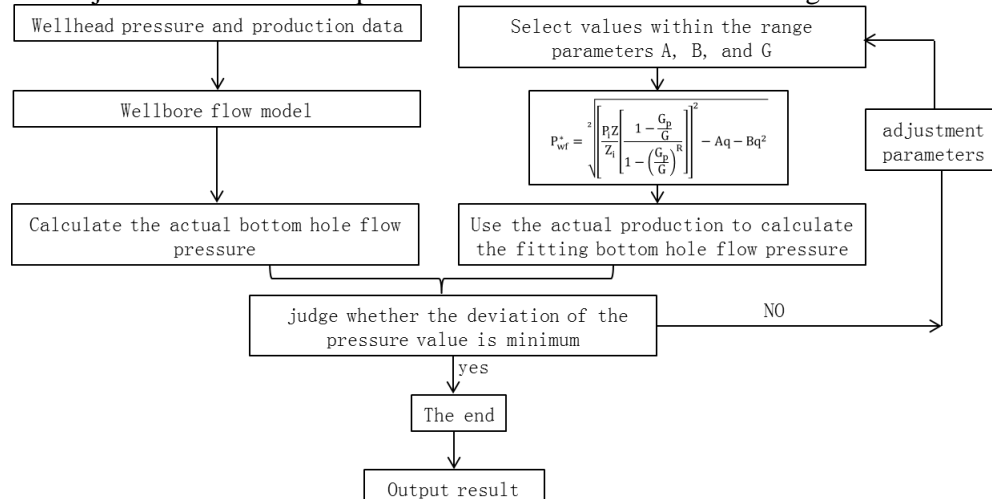

Fig.1   Model solving steps

4. Application example

Taking a typical low-permeability gas reservoir's well A in Dagang oilfield as an example, the original formation pressure of the gas reservoir is 64.73MPa. The productivity equation of gas well is

calculated by using the new method, that comprise with the well test interpretation results, the comparison can verifies the applicability of the new method in calculating productivity equation of low permeability gas reservoir.

4.1. The new method calculates the coefficient of productivity equation
1) Actual bottom-hole flow pressure calculation
    According to the actual gas production, water production and wellhead oil pressure of well A, the wellbore flow model is used to calculate the actual bottom-hole flow pressure of well A.
    2) Flowing pressure fitting
    By adjusting the values of model parameters A, B, G and R, formula (4) is used to calculate the flow pressure values under different production rates, so that the fitting between the calculated flow pressure value and the actual flow pressure value can reach the best. The fitting results are shown in figure 2. The parameters of productivity equation which were calculated by the new method are shown in table 1.
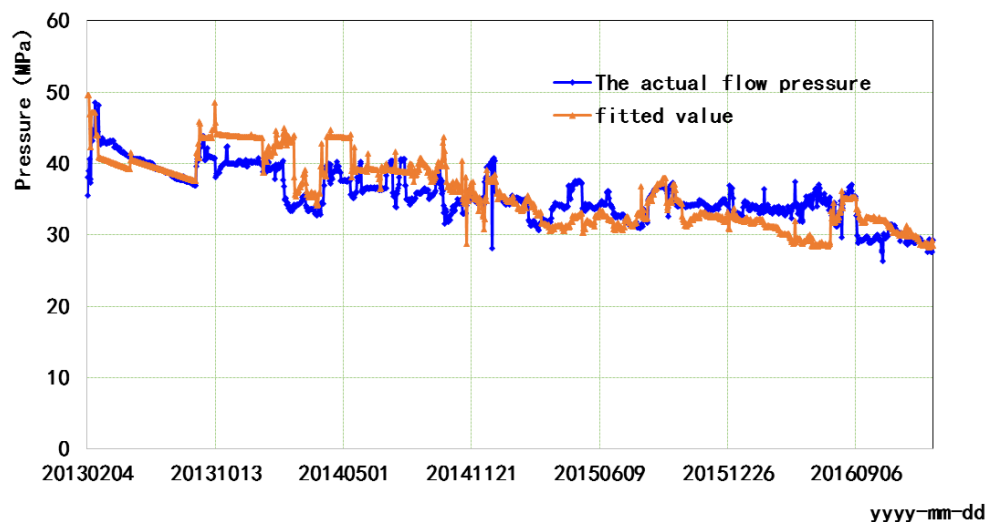

Fig.2   Flowing pressure fitting curve of well A

Table 1.   Well A's parameters were calculated by the new method

data number	Coefficient of productivity equation A	Coefficient of productivity equation B	dynamic reserves $10^8 m^3$	The intensity of water invasion R
143	223.6643	0.9971	1.82	9.16

4.2. Compared with the new method and traditional method
The open flow capacity calculated by the new method is close to the well test interpretation results, as shown in table 2.

Table 2.   Comparison of open-flow potential calculated by the new method and well testing

calculation method	Productivity equation	open-flow capacity $10^4 m^3$
Capacity test	$P^2 - P_{wf}^2 = 182.71Q + 0.763Q^2$	21
New method	$P^2 - P_{wf}^2 = 190.68Q + 0.903Q^2$	20.07

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As can be seen from the table 2, the open-flow potential calculated by the new method is slightly lower than that by the productivity test. The main reason is that the productivity test of the well was carried out at the initial production stage of the gas well, and the productivity equation reflects the productivity of the gas well at the initial stage. As production goes on, low permeability gas reservoir is more and more affected by stress sensitivity; the permeability is reduced compared with the early stage, open flow potential is a decreasing trend. The new method is based on the actual production of the gas reservoir under the influence of stress sensitivity to fit and calculate the coefficient AB value. Considering the influence of stress sensitivity on the production, the new method is slightly lower than the initial value calculated by using well test data, which proves the reliability of the new method.

5. Conclusion
(1) In view of the lack of pressure data in actual gas field production, it is difficult to calculate gas well productivity. This paper according to gas well's existing production data, a new method for calculating coefficient of binomial productivity equation is derived from the basic formula of gas reservoir engineering., the new method without shut-in well to measure pressure, only using production data, we can calculate gas well productivity equation of each production stage.

(2) The calculation results of the new method are consistent with the field practice, which verifies the accuracy of the new method. It is very important to calculate the productivity of low permeability gas reservoir.

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