Research and Application of EUR Prediction Method for Tight Sandstone Gas Wells: Taking Bajiaochang Shaximiao Formation Gas Reservoir as an example

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Abstract: Tight gas is currently an important area for the exploration and development of unconventional oil and gas resources at home and abroad. However, due to the low permeability and high-water saturation characteristics of tight gas reservoirs, gas wells exhibit low productivity, rapid decline in production, and water production in some wells. Such characteristics have reduced the single-well EUR to a certain extent, affecting the recovery rate of the gas reservoir. For new blocks, single-well EUR is the basic condition for long-term high and stable production of oil and gas wells. It is an important indicator for evaluating development effects, analyzing development potential, and formulating development-specific measures. How to quickly and accurately predict and analyze single-well EUR has always been tight Important research work for the development of gas. This paper takes the tight sandstone gas reservoir in the Bajiaochang block as an example. Based on the analysis of the production characteristics of the implemented wells, the production instability analysis method is used to calculate and analyze the single-well EUR and its change at different stages. When the gas well has been producing continuously for more than 2 years, the single-well EUR calculation result is more reliable, Which can reach more than 80% of the final value. This method provides convenience for the rapid and accurate prediction of single-well EUR, and has a better field application effect.

1. Introduction

Tight gas is currently the main target of natural gas development, but due to the particularity of tight gas reservoirs, it exhibits the characteristics of low productivity, rapid decline in production, and low EUR per well during the production process. For single-well EUR forecast analysis, scholars at home and abroad have done a lot of research. At present, the most commonly used method is to use well production data to evaluate EUR. Combined with the analysis of the characteristics of the Shaximiao Formation gas reservoir in the Bajiaochang block, the production instability analysis method is used to calculate and analyze the single-well EUR and its change at different stages. When the gas well has been producing continuously for more than 2 years, the single-well EUR calculation result is more reliable, Which can reach more than 80% of the final value. A single-well EUR prediction analysis chart has been established.
This chart provides convenience for the rapid and accurate prediction of single-well EUR and achieves better on-site application effects.

2. Basic overview of gas reservoirs

The Bajiaochang block is located in Yanting County, Sichuan Province. After the fourth layer of Well J62 was depleted in January 2013, the Shaximiao Formation was tested on gas and the gas production rate was $6.8 \times 10^4 \text{m}^3/\text{d}$, and a gas reservoir in the Shaximiao Formation was discovered. Structurally, the gas reservoir belongs to the central Sichuan paleo-uplift, which is a gentle structure with a burial depth of 1600-3000m. It is a sandy mud deposit dominated by fluvial facies. The thickness of the sand body is 9-40m. The reservoir lithology is composed of feldspar sandstone and lithic feldspar Mainly sandstone, the reservoir permeability is less than 0.1mD, the average reservoir porosity is 8%, the water saturation is 41%, the natural gas density is 0.89, the pressure coefficient is 0.91-0.83, and the temperature is 67-73°C. The gas reservoir is mainly trapped by lithology Restricted by effective reservoir distribution, no water producing wells have been found. It is a lithologic gas reservoir under the background of low gentle anticlines. 15 wells have been put into production. The depletion development is adopted, and no water is produced, but a small amount of condensate oil is produced. The overall development effect is good.

3. Calculation and analysis method of single well EUR

The calculation and analysis method of single well EUR is similar to the calculation method of single well controlled reserves (also known as dynamic reserves) of gas wells. It mainly includes material balance method, production instability analysis method, production decline analysis method and other methods. Different methods adapt to different conditions. Each has its advantages and disadvantages.

3.1. Material balance method

The material balance method is the pressure drop method, based on the principle of conservation of mass, and can be used for almost all types of constant volume elastic gas reservoirs, water drive gas reservoirs, condensate gas reservoirs, abnormally high pressure gas reservoirs, and heterogeneous gas reservoirs with replenishment areas. Calculation of dynamic reserves of type gas reservoirs. This method requires gas reservoirs or gas wells to have a certain degree of recovery, with at least two shut-in pressure measurement data and actual measured flow pressure. When the data is reliable, the material balance method is considered to be the most accurate method for dynamic reserves evaluation.

$$\frac{p}{Z} = \frac{p_i}{Z_i} \left(1 - \frac{G_p}{G}\right)$$  \hspace{1cm} (1)

Among them: $p$—formation pressure, Mpa; $p_i$—formation pressure under original conditions, Mpa; $z$—natural gas compression factor, dimensionless; $z_i$—natural gas compression factor, dimensionless; $G_p$—cumulative gas production, $10^4 \text{m}^3$; $G$—single well controlled reserves, $10^4 \text{m}^3$.

The apparent formation pressure $p/z$ of a gas reservoir or single well has a linear relationship with the cumulative gas production $G_p$, and the cumulative gas production corresponding to $p/z=0$ is extrapolated to the gas reservoir or single well dynamic reserve $G$.

3.2. Yield instability analysis method

The production instability analysis method is based on the theoretical basis of Blasingame et al. and applies the principle of material balance. Based on the analysis of the historical production performance of the gas well, the future production performance is predicted, and the dynamic reserves, reservoir permeability, Parameters such as skin coefficient and drainage area. This method only needs to have certain production data, does not need shut-in pressure measurement data, and the natural gas seepage must reach a pseudo-steady gas well, which can better calculate and analyze the dynamic reserves.

$$\frac{\Delta \psi}{q_g} = m_o t_{ca} + b_{apss}$$  \hspace{1cm} (2)
\[ G = \frac{2p_i}{(\mu c_g Z)_i m_a} \]  \hspace{1cm} (3)

Where:

\[ \Delta \psi = \psi(p_i) - \psi(p_{sof}) \]

\[ t_{wa} = \frac{u c_m}{q_w} \int_{\psi(p_c)}^{\psi(p_i)} \text{d}p \]

\[ m_a = \frac{2p_i}{(\mu c_g Z)_i G} \]

\[ b_{wa} = \frac{1.417 \times 10^4 T_h}{kh} \left( \frac{4 A}{e \gamma C_a p_{sof}} \right) \]

Among them: \( \mu_i, \mu \) — natural gas viscosity under original and current formation pressure, mPa·s; \( c_{gi}, c_g \) — natural gas compression coefficient under original and current formation pressure, 1/MPa; \( k \) — formation permeability, \( \mu m^2 \); \( h \) — effective thickness of the formation, m; \( T \) — initial temperature of the formation, K; \( A \) — discharge area, m²; \( r_{wa} \) — converted radius of the well, m; \( \gamma \) — Euler constant, 0.577216; \( C_a \) — form factor of the formation; \( p_{sof} \) — flow pressure, MPa.

3.3. Production decline analysis method

For all types of oil and gas reservoirs in the declining development stage, the declining analysis method can be used to calculate the dynamic reserves. Arps divides the production decline of gas wells into three types: exponential decline, hyperbolic decline, and harmonic decline. It uses chart fitting to determine decline parameters and predict future performance.

\[ \frac{D_i}{D_t} = \left( \frac{q_i}{q_t} \right)^n \]  \hspace{1cm} (4)

Where: \( D_t \) — initial decline rate, dimensionless; \( q_t \) — initial decreasing output; \( n \) — declining index.

When \( n=0 \), it is exponentially decreasing:

\[ q_t = q_i e^{-D_i t} \]  \hspace{1cm} (5)

When \( n=1 \), it is harmonic decreasing:

\[ q_t = \frac{q_i}{1 + D_i t} \]  \hspace{1cm} (6)

When \( 0<n<1 \), the hyperbola is decreasing:

\[ q_t = \frac{q_i}{(1 + nD_i t)^{1/n}} \]  \hspace{1cm} (7)

4. Evaluation of single well EUR and its changing law

The Bajiao Chang Shaximiao Formation gas reservoir is still in the early and middle stages of development. According to the actual data, the material balance method, production instability analysis method, and decline analysis method are selected to calculate the single well EUR respectively, and the calculation methods are used. For adaptability evaluation, the yield instability analysis method is recommended as the best method.
Table 1. List of calculation methods and applicable conditions for single well EUR

| Classification                  | Calculation method          | Application conditions                                      |
|--------------------------------|-----------------------------|-------------------------------------------------------------|
| Material balance method         | Constant volume gas reservoir | Closed gas reservoir                                         |
|                                | Water drive gas reservoir   | Water flooding index is greater than 0.1                    |
|                                | High pressure gas reservoir | Pressure coefficient is greater than 1.3                    |
|                                | Condensate gas reservoir    | Condensate oil content is greater than 50g/m³               |
| Yield instability analysis      | Fetkovich method            | Various gas reservoirs with constant pressure production    |
|                                | Blasingame method           | conditions and declining production                          |
|                                | Agrawal-Gardner method      | Variable output and pressure, in a state of boundary flow   |
|                                | NPI method                  | control                                                     |
|                                | Production history matching | The water production is small, in the pseudo-steady flow     |
|                                |                             | stage, and the calculation accuracy is high                  |
| Production decline analysis     | Arps decline analysis       | Gas wells and gas reservoirs in the declining stage         |
|                                | Cumulative yield analysis   |                                                             |

Use the production instability analysis method to flexibly calculate the EUR at different production stages of a single well. Typical well: Well J61-3. The EUR for a single well was calculated for 1, 2, 3 and 5 years. The results show that the increase of EUR for a single well slows down in the later period.

Figure 1. Production history fitting curve of J63-1 well in different production stages
5. Single well EUR prediction analysis chart
Due to the low permeability of the reservoir, the fluid seepage and pressure transmission in the tight sandstone gas reservoir are relatively slow, and the control range of the gas well is relatively small in the initial stage of production. The calculated single well EUR is small, and the production time increases. Based on the EUR analysis of 8 test production wells in Bajiaochang with a long production time, focusing on the analysis of the relationship between single well EUR and production time, and performing dimensionless processing, a single well EUR prediction analysis chart of Bajiaochang tight sandstone gas reservoir was established.

![Figure 3. Diagram of EUR prediction and analysis for a single well in the Bajiaochang block](image)

From the single-well EUR prediction analysis chart, it can be seen that with the extension of the production time, the control range of the gas well gradually increases, and the controlled reserves of the single well increase. There are differences in the prediction results of the dynamic reserves at different production stages, but when the gas well has been in continuous production for more than 2 years, the calculation result is more reliable, and the settlement result can reach more than 80% of the final predicted recoverable reserves. The recognition of this law also provides direct guidance for the subsequent calculation of tight gas wells in adjacent blocks.

6. Conclusion
(1) Generally, a single well in tight gas reservoirs does not have a strict stable production period, and there is a decline in production. The unstable flow time is long, and it takes a long time to reach the boundary control flow stage. The method suitable for single well EUR in tight sandstone gas reservoirs
There are material balance method, yield instability analysis method and yield decline analysis method.

(2) Due to the low permeability of the tight sandstone gas reservoir, the fluid seepage and pressure transmission in the formation are relatively slow, and the control range of the gas well is relatively small in the initial stage of production. The calculated single well EUR is small. As the production time gradually increases, the growth rate decreased in the later period, and its single-well EUR curve showed a factory-shaped pattern.

(3) Based on the analysis of the relationship curve between the EUR and the production time of 8 test production wells with a long production time, and the non-dimensioning treatment, a single well EUR prediction analysis chart of Bajiaochang tight sandstone gas reservoir was established.

(4) There are differences in the EUR prediction results of a single well at different production stages. The calculation results are more reliable for more than 2 years of continuous production and can reach more than 80% of the final predicted recoverable reserves, which provides a direct basis for tight gas well EUR prediction.

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