Gas drainage radius evaluation and well pattern optimization of multilayer gas reservoirs

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Abstract. In the development process of shenmu gas field, there are "few wells and low production of reserves; Many wells, high development investment and easy cross-well interference ", it is particularly important to optimize the well spacing of development well pattern. In view of this problem, on the basis of deepening geological understanding, it is necessary to clarify the gas drainage radius of each well, and combine various methods to demonstrate and optimize the well spacing of gas field well pattern.

1. Introduction
Shenmu gas field is a multilayer gas reservoir with no prominent longitudinal predominance. At present, there is a lack of productivity evaluation method for single well of multi-layer system, and the scope of discharge and control factors of small layer of gas well are not clear.

Based on the results of controlling reserves and reservoir physical characteristics of gas Wells of different layers, the gas drainage radius of each layer in typical block is clarified, and the reasonable well spacing is calculated and analyzed. The current method of calculating radius of gas discharge mainly has four kinds: the pressure drop funnel method, well control reserves of backstepping method, frustrated radius analysis method and economic limit well spacing method.

In order to solve the corresponding key technical problems, this paper calculates the deflating radius of shenmu gas field by combining various methods, so as to determine the contribution degree of stratified productivity of multilayer gas reservoirs, and puts forward the optimization scheme of well pattern of multilayer gas reservoirs.

2. Discharge range evaluation method

2.1. pressure drop funnel method
The pressure square variance \((P_e^2 - P_w^2)\) was calculated by using the output formula of the radial flow gas well in the form of pressure square:
\[ q_{sd} = \frac{774.6Kh(p_e^2 - p_{wf}^2)}{T\pi r_p \ln \left(\frac{r_e}{r_w}\right)} \]

Where \( q_{sd} \) is the single well productivity of the perforating unit, \( 10^4 \text{m}^3/\text{d} \); \( K \) is the permeability of the gas layer, \( 10^{-3} \text{m}^2 \); \( h \) is the thickness of the gas layer, \( \text{m} \); \( P_e \) is the supply boundary pressure, \( \text{MPa} \); \( P_{wf} \) is bottom hole pressure (\( \text{MPa} \)); \( T \) is the gas layer temperature, \( \text{K} \); \( \mu \) is the gas viscosity under average pressure and temperature, \( \text{mPa} \cdot \text{s} \); \( \bar{\epsilon} \) is the gas deviation factor under average pressure and temperature; \( r_e \) is the supply boundary radius, \( \text{m} \); \( r_w \) is the gas well radius, \( \text{m} \).

The square distribution expression of stable seepage pressure expressed in the form of pressure square is as equation (2).

\[ p^2 = p_e^2 - \frac{p_e^2 - p_{wf}^2}{\ln \left(\frac{r_e}{r_w}\right)} \ln \frac{r_e}{r_w} \]

Take the value between the bottom hole flow pressure and the formation pressure, calculate the corresponding \( r \) value according to equation (2), and substitute it into the formula to calculate the pressure gradient \( dp/dr \) at any point:

\[ \frac{dp}{dr} = \frac{p_e^2 - p_{wf}^2}{\ln \left(\frac{r_e}{r_w}\right)} \cdot \frac{1}{2pr} \]

Where : \( dp/dr \) is the pressure gradient at any point in the gas layer.

When the pressure gradient is less than the set value, it can be determined that the change of formation pressure tends to slow down, and the corresponding radius \( r \) is the deflating radius \( d \).

2.2. the method of well control dynamic reserve backdating

In this method, the dynamic reserves of a single well are calculated by pressure drop method, and then the control area of a single well is deduced reversely according to the reserves calculation formula of volume method, and the control radius, that is, the control range of a single well, is obtained.

\[ A = \frac{G_0}{0.01dS_oE_ih} \]

Where : \( G_0 \) is well-controlled dynamic reserves, \( 10^8 \text{m}^3 \); \( A \) is the controlled gas-bearing area, \( \text{km}^2 \); \( h \) is the mean effective thickness, \( \text{m} \); \( \phi \) is the average effective porosity, decimal; \( S_0 \) is the average original gas saturation, decimal; \( E_i \) is the expansion coefficient of natural gas.

2.3. analysis of gas radius

According to the theory of unstable seepage flow in natural gas, when gas well unstable seepage, radius of gas well discourage had semilog relationship with permeability. When reach the quasi steady seepage, experience in statistical analysis of low permeability gas reservoir, frustrated radius with reservoir permeability is shown in Figure 2 semilog relationship. According to the shenmu gas permeability distribution histogram (Figure 3), you can see, shenmu gas permeability of the reservoirs are mainly concentrated in the mD (0.2 ~ 0.5), accounting for 78% of the total percentage.
2.4. Economic limit well spacing

According to the balance principle of input and output, the economic limit control reserves of a single well are estimated. Based on the reserves of each development group and the control area of well pattern, the maximum economic limit Wells, well spacing and economic limit well pattern density are calculated.

2.4.1. Economic limit well control reserves

It means that after all the recoverable reserves controlled by a single well have been produced and all of them have been sold, the revenue generated will be used to exactly cover all the investment needed for development and all the taxes for development. The formula is as follows:

\[
G_{el} = \frac{C + tP}{A_G \times E_R}
\]

Where : \(A_G\) is the selling price of natural gas, 0.711 yuan /m³; \(C\) is the total cost of single well drilling and oil construction; \(E_R\) is the natural gas recovery factor, estimated at 0.54; \(P\) is the average annual operating cost of gas recovery per well (648,181 yuan/year · well); \(t\) is the mining life, 25 years; \(G_{el}\) is the economic limit well controlled reserves, \(10^3\) m³.

2.4.2. Economic limit well spacing

Economic limit well spacing refers to the average well spacing when the value of recoverable reserves controlled by a single well is equal to the input cost of gas field construction and single well of gas extraction under certain development and geological conditions.

Formula for calculating economic limit well spacing:

\[
d = 2\left(\frac{A_G \times S_p \times G}{G \times R_{el}}\right)^{1/2}
\]

Where, \(A\) is the distribution area, m²; \(S_p\) is the distribution area/gas-bearing area, and the value of weak edge water reservoir is 0.5. \(G\) is proved geological reserves of natural gas, m³; \(d\) is the economic limit well spacing, m.

Economic limit well pattern density and reasonable well pattern density should be involved in the process of drilling infilling Wells. The economic limit and economic optimal well pattern density of different types under different recovery rates are calculated by gas reservoir engineering method, and the reasonable well pattern density is calculated by adding 1/3 difference method\(^4\).

Table 1. results of reasonable well pattern density and well spacing in vertical/directional Wells

| Recovery / % | Pattern density/ A well• km² | Reasonable spacing |
|--------------|------------------------------|--------------------|
|              | Economic limit method | Economic best practice | Plus one third difference | |
| 30           | 2.69                        | 2.54                | 2.59                        | 538×717m |
| 35           | 3.14                        | 2.93                | 3.00                        | 500×666m |
| 40           | 3.59                        | 3.32                | 3.41                        | 469×625m |
| 45           | 4.04                        | 3.69                | 3.81                        | 444×592m |
| 50           | 4.49                        | 4.06                | 4.20                        | 422×563m |

Figure 2 relationship between discharge radius and reservoir permeability

Figure 3. cumulative frequency distribution of reservoir permeability in shenmu gas field
The calculated results show that the reasonable well spacing at this stage is \((500\times600)m\) for enhanced recovery.

3. Case analysis

Through the above methods, an example of shenmu gas field is analyzed.

The pressure drop funnel method was used to analyze 18 Wells with an average deflating radius of 245.79m. Therefore, the calculated well spacing was about 491.58m. According to the reverse calculation of well-controlled dynamic reserves, it is found that the overall gas drainage radius is 170.8m-254.9m, so the approximate range of reasonable well spacing is 340m-510m. Combined with the empirical method, the relationship between the discharge radius and the reservoir permeability curve, the gas well deflation radius 210m-350m and the reasonable well spacing range 420m-700m were finally determined. The economic limit well spacing is calculated and analyzed to obtain the well spacing under different recovery rates. In order to improve the recovery rate, the reasonable well spacing at the present stage is \(500\times600m\).

Various methods were used to analyze the discharge range and reasonable well spacing in the target block. The results show that the gas deflection radius is about 180m-300m and the reasonable well spacing is about 360m-600m. The research results can be used to guide the well pattern adjustment analysis of the target block, facilitate the fine management of small layers, and improve the overall development benefit.

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