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Study on Rational Well Spacing Optimization of Low Permeability Gas Reservoir

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ABSTRACT

The Shanggu gas field is the low porosity and low permeability. Single well controlled reserves, economic limit well spacing and economic rational spacing through different methods are calculated. With the development experience of Su Lige gas field as guidance, the rational spacing of Shanggu gas reservoir is 700m×900m by calculating daily gas production rate and cumulative gas production with different well spacing using numerical simulation method.

1. Introduction

With the enhancement of development technique of oil and gas field, many low permeability fields, which couldn't yield oil or gas economically in the past, are becoming more and more valuable[1]. We must demonstrate well spacing before or after the development of field [2-4]. Well spacing is of vital importance for ultimate recovery and economic benefit of oil and gas field, especially for low permeability gas reservoir, which is widely reported both at home and abroad[5-15]. Currently, there are two basic methods in papers, which research the rational well spacing of gas field, they are single well controlled reserves and numerical simulation. The well pattern density of low permeability area in Jingbian gas field is low and the control degree of production wells is also low, which are the main reasons why the degree of reserve recovery is low. In order to enhance the producing degree and recovery ratio, well spacing is needed to be changed. Based on the basic principal of well pattern density optimization, rational spacing is economic, should avoid well interference and meet the standard of maximum recovery ratio and producing degree. How can we calculate the rational spacing, which means maximum economic benefit and recovery ration can be achieved with minimum wells? This paper calculates the rational spacing, which is suitable to

Shanggu low permeability gas field, and recommends a rational spacing arrangement.

1) Relationship between Well Spacing And Sand Scale

The main factors affecting the rational spacing are single sand body scale, superposed features of sand body, pattern of composite sand body and sand body's control action of porosity and permeability.

From the results of geologic research, we know that channel width is 60-250 m and channel belt width is 600-2000 m. According to channel belt width, horizontal spacing is 600-1500m. For the same sand body, well spacing is less than channel width (**Table 1**).

2. Methods of Determining Well Spacing

2.1. Single Well Controlled Reserves

Assuming that gas well controlled reserves is known, the sands are uniform throughout the controlled extent of the reservoir, and drainage area is cylinder radial flow area, according to parameters and evaluation result of developed Shanggu gas field, the single well controlled area can be written as

$$A_k = \frac{100 N_k B_g}{p_{or} h s_g} \tag{1}$$

Table 1. Developmental Scale of Neopaleozoic Channel in Gaoqiao.

Zone	Thickness of sand body（m）			Channel width（m）			Channel belt width（m）		
	Min	Max	Variation change	Min	Max	Variation change	Min	Max	Variation change
H$_{8u}$	0.78	9	4-6	8.66	374.3	80-200	38.3	3126.54	750-1600
H$_{8l}$	1	12.2	5-7	12.7	597.98	150-250	59.9	5405.98	1000-2000
S$_1$	0.58	8.06	3-5	5.49	315.82	60-150	22.47	2563.48	600-1200
S$_2$	0.54	8.7	4-5	4.92	355.26	70-180	19.76	2941.45	700-1500

where

A_k-single well controlled area, Km^2; N_k-geologic reserve controlled by single well, 10^8m^3; B_g-gas volume factor, dimensionless; h-Thickness controlled by single well, m; s_g-skin factor, dimensionless.

Single well controlled area is about $0.45Km^2$ by using this method to evaluate 43 gas wells. The well spacing is 0.67Km calculated by square area.

2.2. Economic Limit Spacing

Economic limit spacing is the minimum spacing in terms of economic benefit. Economic limit spacing is in direct correlation with economic limit reserve. Under the condition of without considering the risk of drilling and considering the cost of drilling engineering and surface construction, the operation cost of gas production, the selling price of gas and the loan interest rate, etc, the equation of production well spacing using economic limit spacing method can be written as

Gross input of certain pattern density:

$$C_{in} = A \cdot S (I_D + I_F + I_B)(1+R)^{(T_1+T_2+T_3)/2} \qquad (2)$$

Gross output of this pattern density:

$$C_{out} = 10 \cdot N \cdot E_R \cdot C(P_g - O - T_{ax}) \qquad (3)$$

Gross profit:

$$G = C_{in} - C_{out} \qquad (4)$$

When gross profit equals to zero, the pattern density is limit pattern density:

$$G = C_{in} - C_{out} = 0 \qquad (5)$$

Then, economic limit pattern density S is

$$S = \frac{10 \cdot N \cdot E_R \cdot C(P_g - O - T_{ax})}{A(I_D + I_F + I_B)(1+R)^{(T_1+T_2)/2}} \qquad (6)$$

$$L_{min} = \sqrt{\frac{1}{S}} \qquad (7)$$

According to the development experience of Jingbian gas field, we know that when average reserves abundance is larger than $1.1 \times 108m3d/km2$, the economic limit spacing is smaller than 0.700km.

Where

S-economic limit pattern density, wells/Km^2; ID-drilling cost of single well(includes perforation, test, logging and so on), 104 yuan/well; IF-fracturing cost of single well, 10^4 yuan/well; I_B-surface construction cost of single well(includes system engineering, field construction, etc), 10^4 yuan/well; P_g-selling price of gas, yuan/10^3m^3; C-commodity rate of gas, ratio; O-operation cost of gas, yuan/10^3m^3; Tax-toll of gas, yuan/10^3m^3; A-gas bearing area, km^2; R-yearly loan interest rate, ratio; N-gas in place, 10^8m^3; E_R-recovery ratio with pattern density being S, ratio; C_m-gross input,10^4 yuan; C_{out}-gross output,10^4

yuan; G-gross profit, 10^4 yuan; T_1-years of stable production, year; T_2-decreasing years with decline fraction being 20%, year; L_{min}-economic limit spacing, km.

2.3. Rational Spacing

Economic limit spacing is rational pattern density with certain profit. If considering the profit is 0.2 times of selling price, then

$$S = \frac{10 \cdot N \cdot E_R \cdot C(P_g - O - T_{ax} - 0.2P_g)}{A(I_D + I_F + I_B)(1+R)^{(T_1+T_2)/2}} \qquad (8)$$

Superimposed with Shanggu reserves, we know that average reserves abundance is larger than $1.1 \times 10^8m^3d/km^2$. The economic limit spacing is smaller than 0.834km.

3. Rational Spacing Determined by Numerical Simulation

On the basis of geologic model, we found mechanism model of Shan 135 well and G61-11 well. Basic parameters of mechanism model are length and width: 5000×6000m, grid spacing: 100 × 100m, reserves abundance: $1\times10^8m^3/km^2$, five zones in vertical, which corresponds to subzone, namely, H_8, S_1, S_2, Benxi, without considering Xiagu reservoir.

We consider 8 combinations of well spacing/horizontal range, as shown in **Table 2**. Results are listed in **Figure 2**, **Figure 3** and **Table 3**. When individual well producing rate is $1\times10^4m^3$/d and comparing calculation results of different well spacing and horizontal range, we conclude that the shorter the well spacing is, the more the well number is and the higher the gas production rate is, the shorter the years of stable production is. When well spacing/horizontal range is 700×900m, years of stable production is 3 years and both the gas production rate and recovery ratio is relatively high.
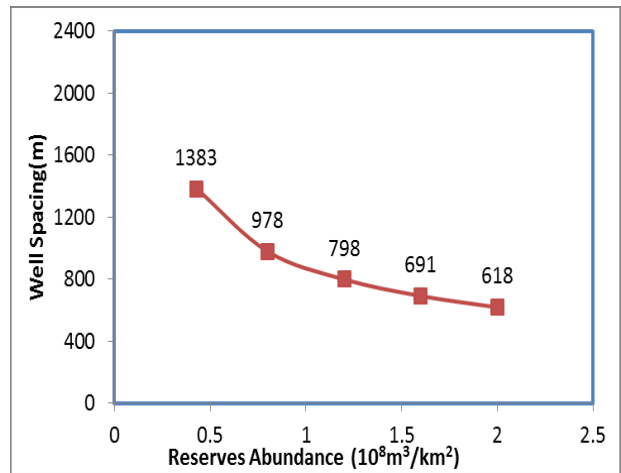

Figure 1. Relationship Graph between Economic Rational Spacing and Reserves Abundance of Ancient Gas Field.

Table 2. Design Table with Well Spacing/Horizontal Range.

Well Spacing （m）	1100	1000	900	800	700	600	600
Horizontal Range （m）	1300	1200	1100	1000	900	800	750

Table 3. Statistical List of Optimum Spacing and Horizontal Range of Ancient Gas Field.

Project No.	1	2	3	4	5	6	7
Well Spacing（m）	1100	1000	900	800	700	600	600
Horizontal Range（m）	1300	1200	1100	1000	900	800	750
Number of wells（well）	20	25	30	36	50	56	64
Years of Stable Production（year）	9.4	6.2	4.8	4.2	3.2	2.4	2.2
Daily Gas Production（$10^4 m^3$/d）	20	25	30	36	50	56	64
Gas Production Rate（%）	2	2.6	3.1	3.7	5.1	5.7	6.5
Cumulative Production at the end of Stable Production（$10^8 m^3$）	5.41	5.53	5.64	5.82	5.94	6.10	6.34
Degree of Reserve Recovery at the end of Stable Production（%）	16.72	17.08	17.44	17.99	18.36	18.85	19.58
Cumulative Production after 20 Years（$10^8 m^3$）	10.86	11.35	12.09	13.04	14.18	14.56	14.97
Degree of Reserve Recovery after 20 Years（%）	33.55	35.08	37.37	40.30	43.83	44.98	46.25
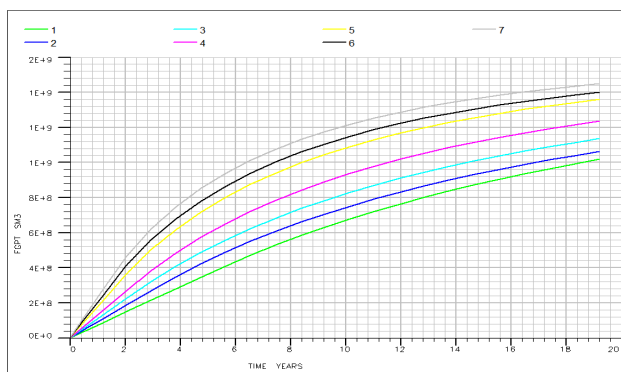
Figure 2. Cumulative Production Comparison Graph with Different Spacing and Horizontal Range.
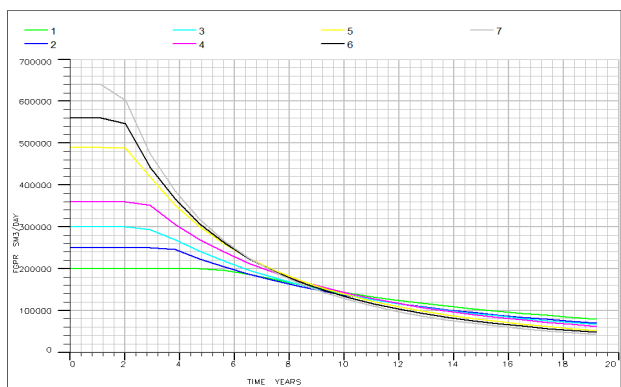
Figure 3. Daily Gas Production Comparison Graph with Different Spacing and Horizontal Range.

4. Determination of Rational Spacing In Shang Gu Gas Reservoir

Reserves abundance of Su Lige gas field is $1.2 \times 10^8 m^3/km^2$ and rational spacing and horizontal range is 600m×800m. Reserves abundances of project area which is larger than $0.5 \times 10^8 m^3/km^2$ are 2612.07km², which accounts for 60% of total area. Average reserves abundance is $1.16 \times 10^8 m3/km^2$ and geologic reserve is $3030 \times 10^8 m^3$, which accounts for 79.77% of Shanggu gas reserve, whose reserves is $3798.62 \times 10^8 m^3$. So rational spacing and horizontal range of project area is larger than 600m×800m.

Shanggu Gas reserves abundance of project area which is larger than $0.5 \times 10^8 m^3/km^2$ accounts for 79.77% of gas reserve. So the rational spacing and horizontal range is 700m×900m.

5. Conclusions

1) Rational pattern density not only meets the requirement of development of gas field but should ensure maximum economic benefit. Rational pattern density is determined by geologic characteristic of gas field.

2) This paper determines the rational spacing of low permeability area in ancient gas field is 700m×900m by using economic limit spacing, economic rational spacing and numerical simulation. And this paper demonstrates an effective way of determining rational spacing and spacing arrangement of low permeability gas reservoir.

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