Study on Well Spacing Optimization in Tight Sandstone Gas Reservoir

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Summary

Compared to the shale gas and coalbed methane, tight gas should be considered in priority in the exploration and exploitation of unconventional gas in China[1]. In the development of tight gas field, how to enhance the gas recovery is a prevalent topic. Unlike conventional gas reservoir, the ultimate gas recovery is not only determined by the geological characteristics but also affected by other factors such as well drainage area and well spacing design. Therefore, Effective drainage area estimation and well spacing optimization are essential aspects for tight gas recovery enhancement. And a thorough optimization method need to be established. For tight sandstone reservoir, the gas recovery can be improved by increasing the drainage area. And the well drainage area is closely associated with well spacing pattern. Therefore, well spacing optimization can be an effective method to enhance gas recovery in tight gas field. In the case of Sulige gas field, the single well drainage area is estimated and well spacing optimization result is obtained by combining gas reservoir engineering method and numerical simulation method. And by optimizing the drainage area and well spacing pattern, the gas recovery could be improved.

Introduction

The percentage of natural gas in the world energy comsumption is progressively increasing. Some projections points out that natural gas comsumption will surpass oil and coal, becaming first position of fossil fuel energy by 2030[2-4]. This upcoming change meets the common demands for environment friendly and sustainable development all around the world. In recent years, unconventional gas including tight gas, shale gas and coalbed methane plays more and more important part and contributes 24% of the total global natural gas output $3.55\times10^{12}m^3$ in 2016. For China, tight gas is potentially the most attactive clean energy currently. In the year of 2016, the production of tight sandstone gas in China exceeds $400\times10^8m^3$, accounting for about 30% of the total natural gas production. Whereas there are many difficulties and challenges in tight gas reservoir exploitation in China. One critical problem is low gas recovery which affected by single well drainage area. And it is widely known that gas well drainage area is associated with the the well pattern. Improper well spacing may cause lower single well production, fast decline of gas rate or lower ultimate gas recovery. Therefore, a thorough approach of well spacing design for tight gas is urgently needed. At present, the methods of optimizing well pattern of tight gas reservoirs domestic and overseas mainly include geostatistical method[5, 6], production potential method[7, 8], gas reservoir engineering method[9, 10] and numerical simulation method[11].

Theory

Effective drainage area estimation. For conventional gas reservoir, the ultimate recovery is determined by the geological characteristics of reservoir itself when depletion explotation is applied. While for unconventional gas reservoir, it will be a different situation. Because of the extremely low permeability and complex pore throat structure, the drainage area is far from the ideal reservoir and becomes the key factor that affect the ultimate gas recovery. Decline curve analysis, material balance equation and production analysis are widely used to estimatie the drainage of tight gas well. Gas production analysis is a type curve matching technique used in formation property interpretation. The constant rate time analogy time function is defined as the ratio of the cumulative output and the flow rate, $t_{cr}=\frac{Q(t)}{q(t)}$, when the normalized rate

$\frac{q(t)}{p_i - p_w(t)}$ is plotted versus this function on a log-log scale, the boundary dominated flow period follows a negative unit slope line. Based on this result, Palacio and Blasingame introduced type-curves that could be used for variable flowing pressure conditions[12]. Due to the noise of the production data, the derivative was not applied to the normalized flow itself but to its integral. The normalized rate(PI), normalized rate integral(PI_{Int}) and normalized rate integral derivative($PI_{Int}{}'$) were defined as followed: $PI(t)=\frac{q(t)}{p_i - p_w(t)}$, $PI\_Int = \frac{1}{t_e}\int_0^{t_e} PI(\tau)d\tau = \frac{1}{t_e}\int_0^{t_e} \frac{q(\tau)}{p_i - p_w(\tau)}d\tau$, $PI_{Int}{}' = \frac{\partial(PI_{Int})}{\partial \ln(t_e)}$. Figure 1 shows the typical type curve for a particular well model. Since the compressibility of gas must be considered, the p(t) should be replaced by $m(p) = 2\int_0^p \frac{p}{\mu Z}dp$.

Interference well test. Interference well test was carried out in the target field with pressure measuring equipments installed at the bottom of the selected wells. Interference probability(F) can be defined as the ratio between the amount of interfered wells(n_i) and total wells(n_{total}): $F = \frac{n_i}{n_{total}}$ [13]. The interference probability can represent the well density of the gas field. There is a relatively good relationship between the two factors. That is when the reservoir is developed with a dense well pattern, the well interference happens more often, so the interference probability is higher, otherwise, when the well density is low, the interference probability is lower.

Example

The well spacing optimization method is applied in the case of Sulige tight gas field, a typical tight sandstone gas reservoir featured by low permeability, small scale sand bodies and heterogeneity located in the Ordos Basin China. After more than 15 years exploitation, means to enhance the gas recovery become the key topics in the future development project. With the development of the reservoir, some newly drilled wells are added to the original well pattern design. The current well spacing is close to 800m×900m. According to researches on ultimate recovery in tight gas reservoir, the gas recovery of Sulige could be further improved by increasing the drainage area. An effective way to extend gas field drainage area is well spacing optimization.

Single well drainage area estimation. In the target block, production data of 56 wells are gathered for calculating current single well drainage area. Most of these wells can provide more than 5-year production date. Analyzing with production analysis method, the estimated results are shown in Figure 2. It indicates that after about 10-year development, the average single well drainage area is 0.2km^2 currently, and more than 90% of the 56 wells' drainage area are less than 0.4km^2. Meanwhile, 37 groups of interference well test are carried out. By analyzing the well test data, the relationship between well density and interference probability can be obtained. As shown in the Figure 3, if the well density is lower than 2.5, the probability is close to 0, means no interference happens, while when the well density is higher than 6.7, the interference probability almost reaches 100%. This can be a guidance in the well spacing optimization.

Numerical simulation. According to the geological characteristics of Ordos Basin (Figure 4), the simulation model is set up. And 14 simulation cases are designed conducted with different well spacings and well arrays (Table 1), The well spacing ranges from 400m to 1200m and well array ranges from 600m to 1200m. There are 2 parts in the simulation. The first one is changing well array with constant well spacing. And the second one is changing well spacing with fixed well array to optimize the well pattern. The simulation results show that the single well cumulative gas volume increases when the well array increases, but there is a special point at 800m (Figure 5), from where the slope of curve turns flat. Therefore, 600m should be considered the optimal well array. In the same way, 600m should be the optimal well spacing (Figure 6).

Table1. Well spacing design for numerical simulation

Well array	600	800	1000	1200
Well spacing	600	800	1000	1200
	400	600	800	1000
		400	600	800
			400	600
				400

Conclusions

In tight sandstone gas field, well drainage area is closely related to tight gas recovery. While the well drainage area can be improved by optimizing the well placing pattern. In this paper, an approach to optimize well spacing in tight gas is presented through engineering method and numerical simulation method. The method established can be used to help determine well pattern design both for new gas field and mature gas reservoir. Meanwhile, with the development of tight gas field more production data can be used to estimate appropriate single well drainage area which is crucial to well pattern design, the ultimate gas recovery would be further improved.

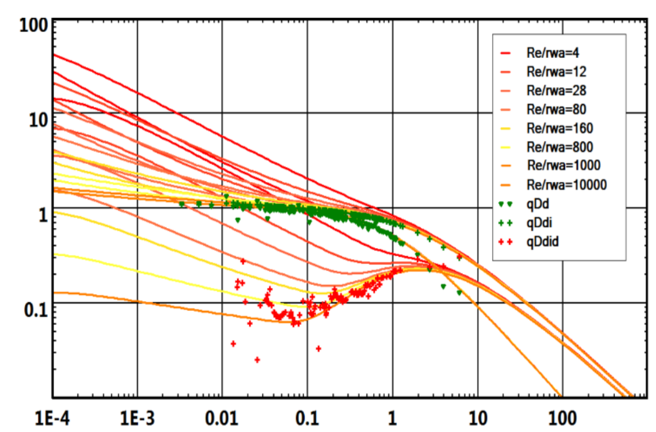


Figure1. Typical type curve application

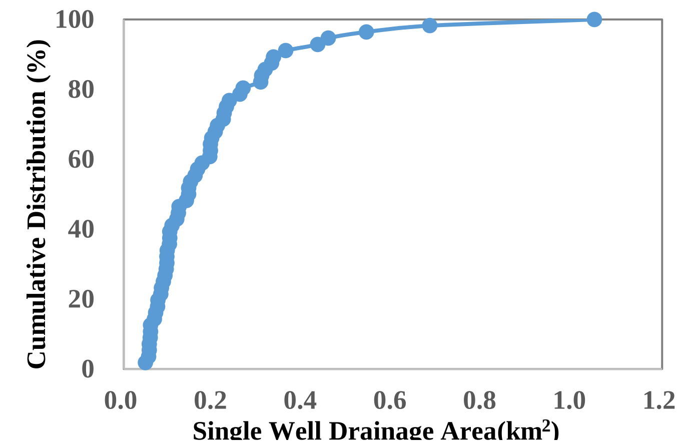
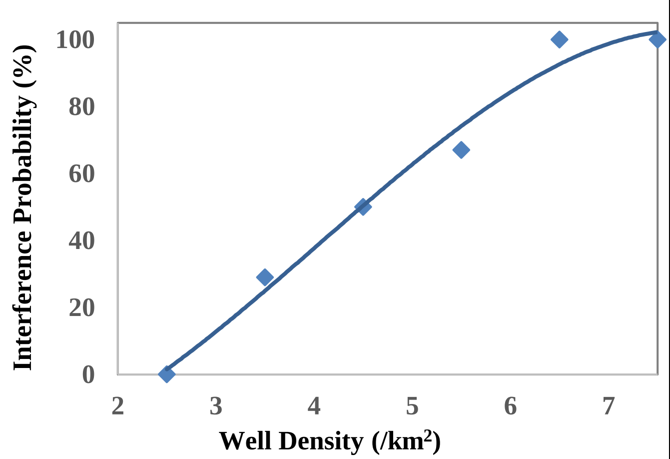


Figure2. Cumulative distribution of single well drainage area



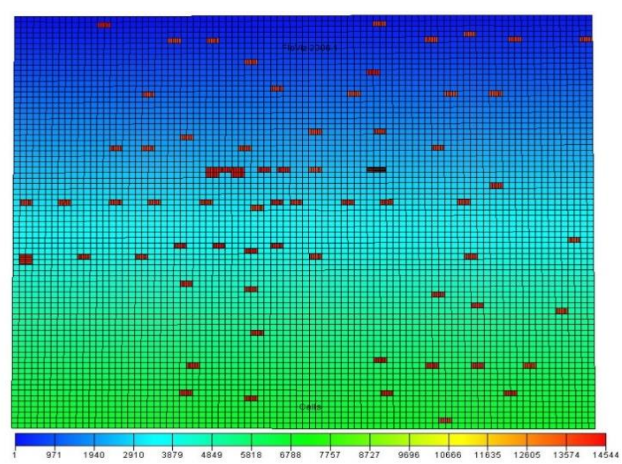


Figure3. Relationship between well density and interference probability	Figure4. Gridding of geological model of target block

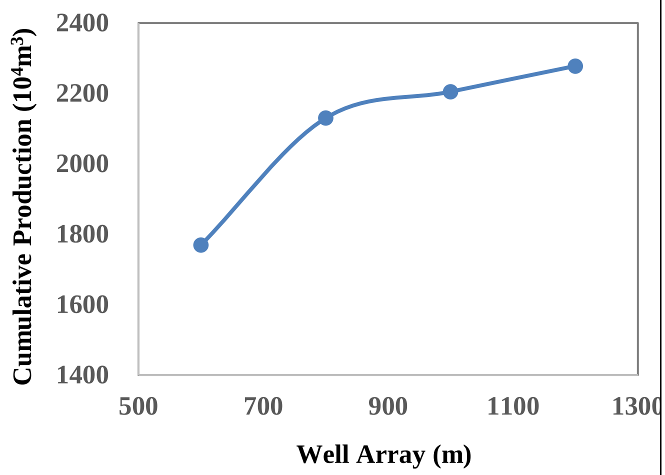


Figure5. Well arrray optimization(well spacing=800)

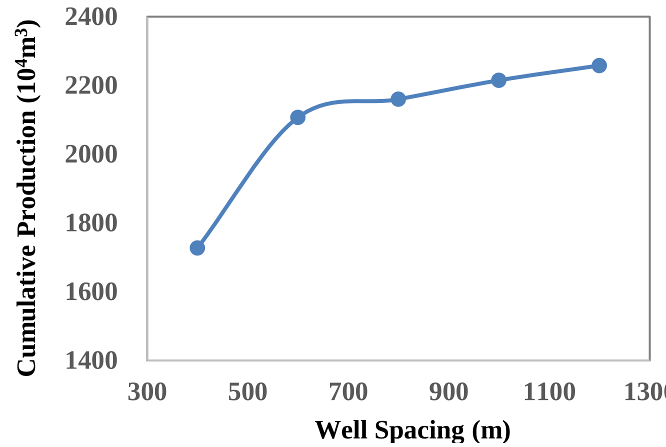


Figure6. Well spacing optimization(well array=800)

Novel Information

A well pattern optimization method was proposed combing empirical method and numerical simulation method. In addition, the single well drainage of tight sandstone gas well is studied which is crucial to enhance gas recovery in tight gas field development.

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