Simulation Study on the Influence of Fracture Distribution Mode on Gas Production in Horizontal Wells in Tight Sandstone Gas Reservoir

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Abstract. Horizontal well-staged fracturing technology is the most important stimulation technology for the development of tight sandstone oil and gas reservoirs. However, when using this technology to develop tight sandstone gas reservoirs, there are still some problems. Traditional fracture layout theory can no longer meet the increasingly complex well conditions. Therefore, it is urgent to compare conventional and unconventional fracture layout methods according to the characteristics of tight sandstone gas reservoirs. To guide the development of tight sandstone gas reservoirs with the lowest fracturing cost and the highest productivity, comprehensive and systematic research is needed. Therefore, based on the gas reservoir numerical simulation theory combined with fracturing numerical simulation software, this paper analyzes the influence of different factors and different combinations of fractures on gas production in the tight sandstone gas reservoir of Sulige Gas Field. Combining numerical simulation results and orthogonal experiments, the horizontal well fracturing layout plan is optimized. The simulation results show that the stimulation effect is better when the segmented fractures are distributed symmetrically along the central axis of the horizontal wellbore; when the segmented fracture spacing is small at both ends and the middle is large, the adjacent fracture spacing ratio is 0.9 when the production effect is the best; When the two ends of the fracture length are long and the middle is short, the production effect is best when the ratio of adjacent fracture lengths is 0.8; the orthogonal experiment results show that the segmented fracture length has a greater impact on gas production than the segmented fracture spacing. The simulation of the unconventional way of laying joints shows that the gas production is higher when the joints are placed in locations where relatively higher gas saturation and permeability exist, and the distribution of natural fractures will further increase the gas production.

Keywords: Tight sandstone gas · Horizontal well fracturing · Fracture arrangement · Optimization design

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1 Introduction

Horizontal well staged fracturing technology is a key technology to promote the industrial development of tight sandstone gas reservoirs. By studying the fracture parameters of horizontal wells, the fracture distribution plan can effectively improve the stimulation effect of the horizontal well staged fracturing technology, which is of great significance for fracturing construction and economic production of tight sandstone gas reservoirs. Nicolas P. Roussel (2011), Chuang Liu (2016), et al. established different numerical models to study the optimal fracture spacing of horizontal wells for continuous fracturing, alternating fracturing, and simultaneous fracturing [1, 2]. A. Belyadi (2010), Didier Yu Ding (2014), Desheng Zhou (2015), et al. studied the effects of fracture spacing and number of fractures on the productivity of horizontal wells after fracturing [3–7]. Nguyen (2015), Kolawole, O. (2019), et al. studied the effects of matrix permeability, fracture half-length, fracture spacing, rock compressibility, proppant type, and fracturing fluid type on hydraulic fracturing design [8–10]. YE Aimene (2015), F Zhang (2019), Kolawole, O. (2019), Yao Wenli (2020), et al. analyzed the interaction between natural fractures and hydraulic fracturing combined with numerical simulation software and cases [11–16]. However, they have not conducted a systematic study on the conventional and unconventional fracture distribution mechanism of tight sandstone gas reservoirs. Therefore, this article will focus on the tight sandstone gas reservoirs in the Ordos Basin, based on the gas reservoir numerical simulation theory, use wellwhiz fracturing numerical simulation software, analyze the influence of different factors and different combinations of fractures on the gas production of horizontal wells and optimize the design of the fracture distribution plan for horizontal wells [17]. The specific work is as follows. First, a conventional fracture distribution simulation model and an unconventional fracture distribution simulation model are established, then the adjacent spacing ratio and the adjacent fractures length ratio two conventional factors are studied, and the degree of influence of the two on gas production is determined through orthogonal experiment, then the influence of three unconventional factors, gas saturation, permeability, and natural fractures on gas production are analyzed. Finally, conclusions are summarized. This study has guiding significance for the fracturing design of horizontal wells in tight sandstone gas reservoirs.

2 Model Building

In this design, well01 in Block N of Sulige Gas Field was selected. According to the principle of gas well productivity fitting, a horizontal well fracturing conventional fracture distribution simulation model is established by Wellwhiz fracturing simulation software (Fig. 1-a). In order to study the influence of unconventional fracture distribution methods on gas production, a gas saturation model (Fig. 1-b) and a permeability model (Fig. 1-c) is established by dividing the horizontal section into several areas on the basis of the conventional fracture distribution simulation model and modifying the gas saturation value or permeability value of each area; A natural fracture model is established by refining the grid around the fractures and modifying the permeability value in the refined grid to add natural fractures (Fig. 1-d).

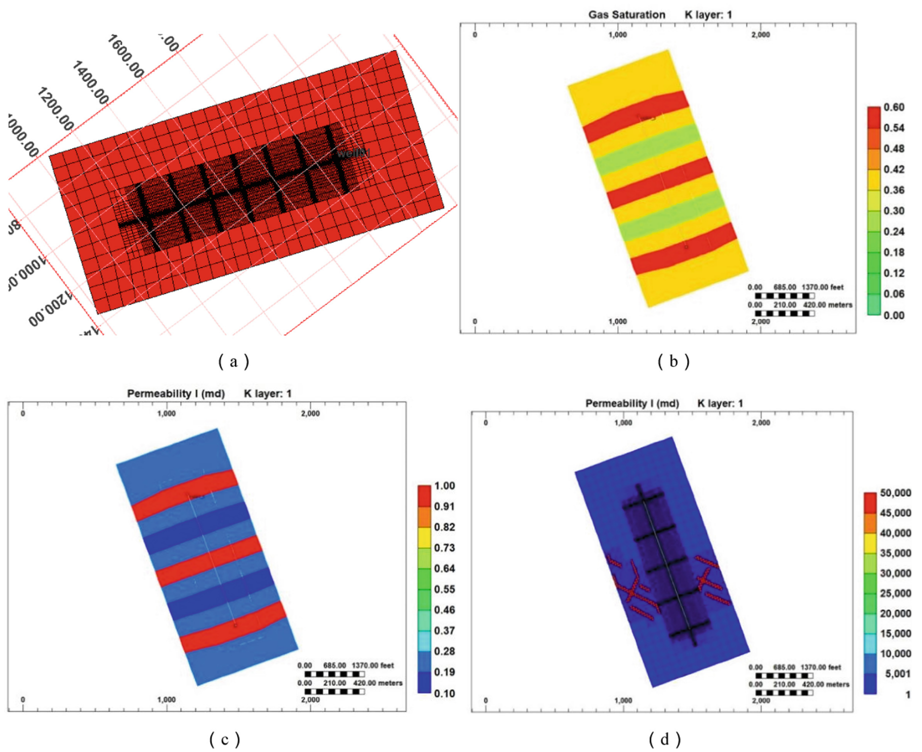


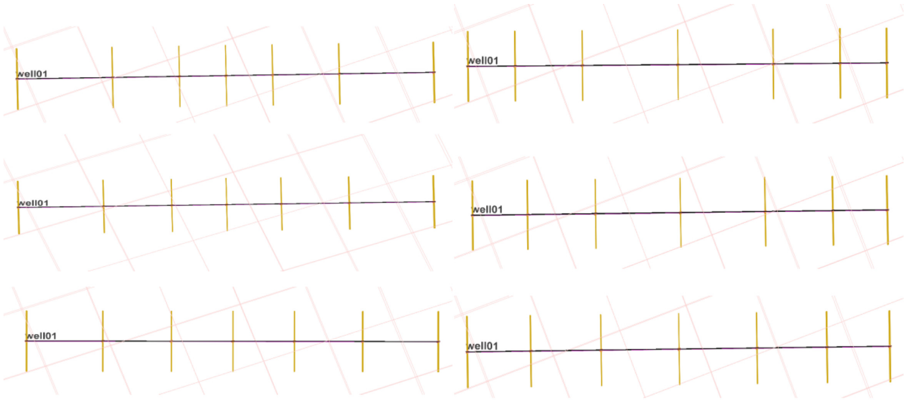
Fig. 1. Basic simulation model of well01

3 The Influence of Different Adjacent Fracture Spacing Ratios and Adjacent Fracture Length Ratios on Gas Production

Adjacent fracture spacing ratio refers to the ratio of the distance between two adjacent fractures, and adjacent fracture length ratio refers to the ratio of the length of two adjacent fractures. Both can be used to characterize the non-uniform distribution of fractures along the horizontal wellbore. When the fracture length at both ends of the horizontal wellbore is long and the fracture spacing is small, the gas production is high, but due to the influence of the interference among fractures and the interference of the exhaust boundary, within a certain range, there is an optimal value plan to increase the gas production by increasing the fracture length and reducing the fracture spacing. In this section, through the horizontal well conventional fracture distribution simulation model, combined with the orthogonal experiment, the influence of adjacent fractures spacing ratio and adjacent fractures length ratio on the gas production are analyzed, and the optimal fracture distribution plan is determined. The basic fracture parameters of the model are that the length of the horizontal well section is 1000 m, the number of fractures is 7, the fracture spacing is 150 m, the fracture half-length is 120 m, and the fracture flow conductivity is 12 $\mu m^2 \cdot cm$.

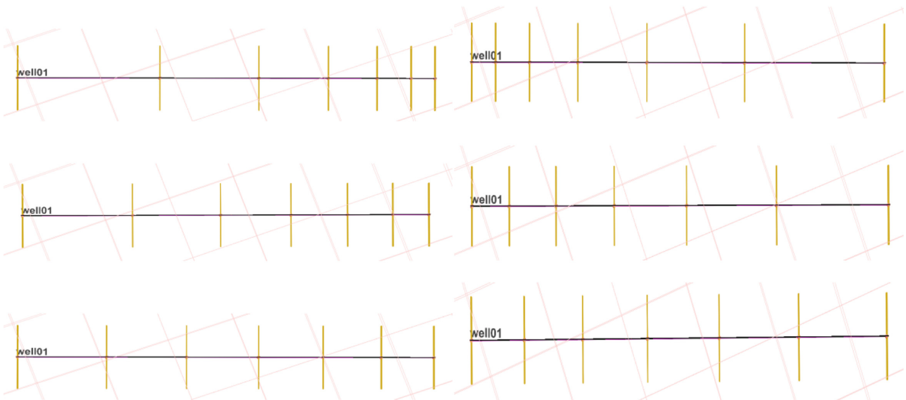
3.1 The Influence of Different Adjacent Fracture Spacing Ratios on Gas Production

Symmetrical type adjacent fracture spacing ratio is the ratio of the next fracture spacing from the root fracture to the middle fracture part to the previous fracture spacing, and the asymmetric type adjacent fracture spacing ratio is the ratio of the next fracture spacing to the previous fracture spacing. In order to study the influence of different adjacent fracture spacing ratios on gas production, four types of fracture distribution methods with different adjacent fracture spacing ratios of symmetrical and asymmetrical types were simulated and analyzed (Fig. 2). Table 1 shows the cumulative gas production after three years of fracturing, it can be seen when the fracture distribution is symmetrical and



Symmetrical adjacent fracture spacing ratios （less than 1）is 0.7、0.8、0.9

Symmetrical adjacent fracture spacing ratios （greater than 1）is 0.7、0.8、0.9



Asymmetrical adjacent fracture spacing ratios （less than 1）is 0.7、0.8、0.9

Asymmetrical adjacent fracture spacing ratios （greater than 1）is 0.7、0.8、0.9

Fig. 2. Simulation diagram of fracture distribution under different adjacent fracture spacing ratios

the adjacent fracture spacing ratio is 0.9 (greater than 1), the cumulative gas production of gas well is the highest after three years of fracturing.

Table 1. Cumulative production of gas well with different adjacent fracture spacing ratios

Adjacent fracture spacing ratios	Simulation time (year)	Cumulative gas production of symmetrical adjacent fracture spacing ratio (less than 1) $10^4(m^3)$	Cumulative gas production of symmetrical adjacent fracture spacing ratio (greater than 1) $10^4(m^3)$	Cumulative gas production of asymmetrical adjacent fracture spacing ratio (less than 1)$10^4(m^3)$	Cumulative gas production of asymmetrical adjacent fracture spacing ratio (greater than 1) $10^4(m^3)$
0.7	3	2114.45	2124.81	2070.99	2086.03
0.8	3	2119.97	2125.93	2099.32	2110.73
0.9	3	2123.26	2126.77	2119.09	2124.48

3.2 The Influence of Different Adjacent Fracture Length Ratios on Gas Production

Symmetrical type adjacent fracture length ratio is the ratio of the next fracture length from the root fracture to the middle fracture part to the previous fracture length, and the asymmetric type adjacent fracture length ratio is the ratio of the next fracture length to the previous fracture length. In order to study the influence of different adjacent fracture length ratios on gas production, four types of fracture distribution methods with different adjacent fracture length ratios of symmetrical and asymmetrical types were simulated and analyzed (Fig. 3). Table 2 shows the cumulative gas production after three years of fracturing, it can be seen when the fracture distribution is symmetrical and the adjacent fracture length ratio is 0.8 (less than 1), the cumulative gas production of gas well is the highest after three years of fracturing.

3.3 Use the Orthogonal Test Method to Comprehensively Study the Influence of Adjacent Fracture Spacing Ratio and Adjacent Fracture Length Ratio on Gas Production

Through the orthogonal test method, the order of the influence of adjacent fractures spacing ratio and adjacent fractures length ratio on the cumulative gas production are analyzed, so as to determine the optimal fracture distribution plan. It can be seen from the orthogonal test stable (Table 3), the order of influence on gas production are adjacent fractures spacing ratio and adjacent fractures length ratio. The optimal combination of fracture distribution plan is as follows: the symmetrical type adjacent fracture spacing ratio is 0.7 (greater than 1) and the symmetrical type adjacent fracture length ratio is 0.9 (less than 1).

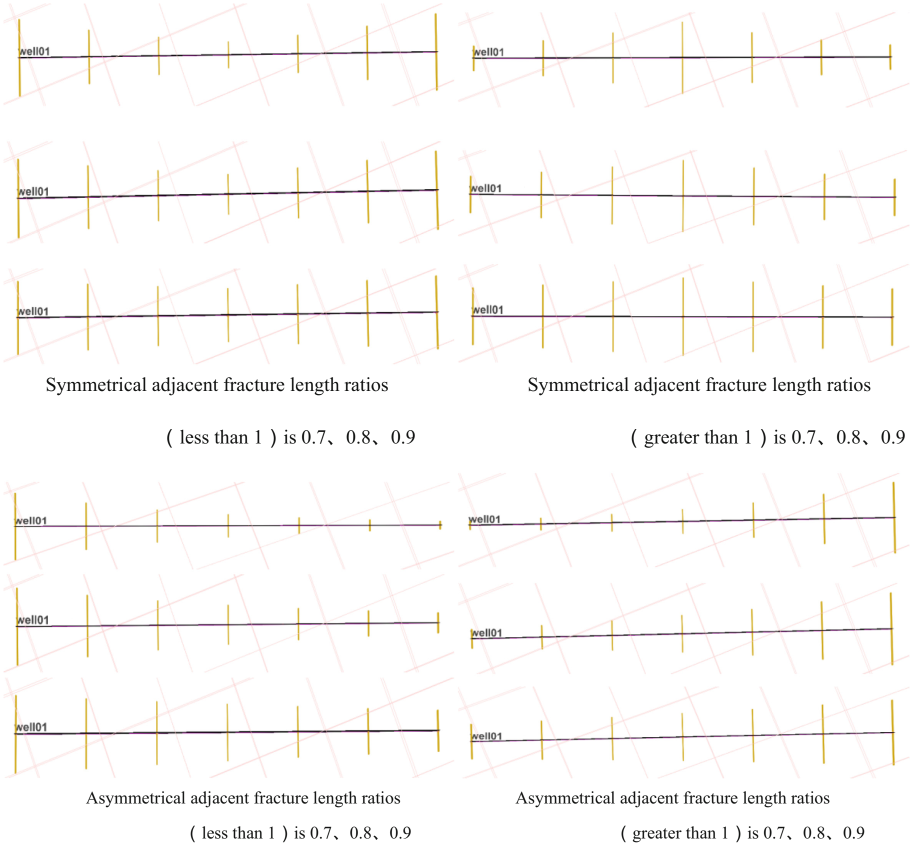


Fig. 3. Simulation diagram of fracture distribution under different adjacent fracture length ratios

Table 2. Cumulative production of gas well with different adjacent fracture length ratios

Adjacent fracture length ratios	Simulation time (year)	Cumulative gas production of symmetrical adjacent fracture length ratio (less than 1)$10^4(m^3)$	Cumulative gas production of symmetrical adjacent fracture length ratio (greater than 1) $10^4(m^3)$	Cumulative gas production of asymmetrical adjacent fracture length ratio (less than 1)$10^4(m^3)$	Cumulative gas production of asymmetrical adjacent fracture length ratio (greater than 1) $10^4(m^3)$
0.7	3	2126.74	2084.96	2110.94	1980.56
0.8	3	2129.16	2107.18	2124.74	2041.87
0.9	3	2127.51	2117.4	2126.86	2103.19

Table 3. Orthogonal test scheme table

Item		Factor		
		A(Adjacent fracture spacing ratios)	B(Adjacent fracture length ratios)	Cumulative gas production $10^4(m^3)$
Level	1	0.7	0.7	2126.83
	2	0.7	0.8	2128.87
	3	0.7	0.9	2130.22
	4	0.8	0.7	2125.67
	5	0.8	0.8	2130.11
	6	0.8	0.9	2129.66
	7	0.9	0.7	2128.25
	8	0.9	0.8	2128.25
	9	0.9	0.9	2128.77
	K_1	6385.92	6380.75	
	K_2	6385.44	6387.23	
	K_3	6385.27	6388.65	
	$\overline{K_1}$	2128.64	2126.92	
	$\overline{K_2}$	2128.48	2129.08	
	$\overline{K_3}$	2128.42	2129.55	
	R	0.22	2.63	

4 Simulation Study on the Influence of Unconventional Fracture Distribution of Horizontal Well on Gas Production

4.1 Influence of Reservoir Physical Properties on Gas Production

Gas saturation and permeability are important factors affecting gas production in tight sandstone reservoirs. Therefore, this section studies the influence of gas saturation and permeability on gas production. Through the establishment of gas saturation model and permeability model simulation, the influence of fracture distribution in different gas saturation locations and different permeability locations on gas production is analyzed. The basic fracture parameters of the model are that the length of the horizontal section is 1000 m, the number of fractures is 5, the fracture half-length is 100 m, and the fracture spacing is 200 m.

As shown in Fig. 4, the influence of fractures distribution in six different reservoir physical properties location on gas production is analyzed, at high gas saturation (4-a), low gas saturation (4-b), medium gas saturation (4-c), and high permeability (4-d), low permeability (4-e), medium permeability (4-f). Table 4 shows the cumulative gas production after three years of fracturing under the six plans. It can be seen when the fractures are placed at locations with high gas saturation and locations with high permeability, respectively, the gas production is the highest. Therefore, the fractures should be placed at locations with high gas saturation and high permeability.

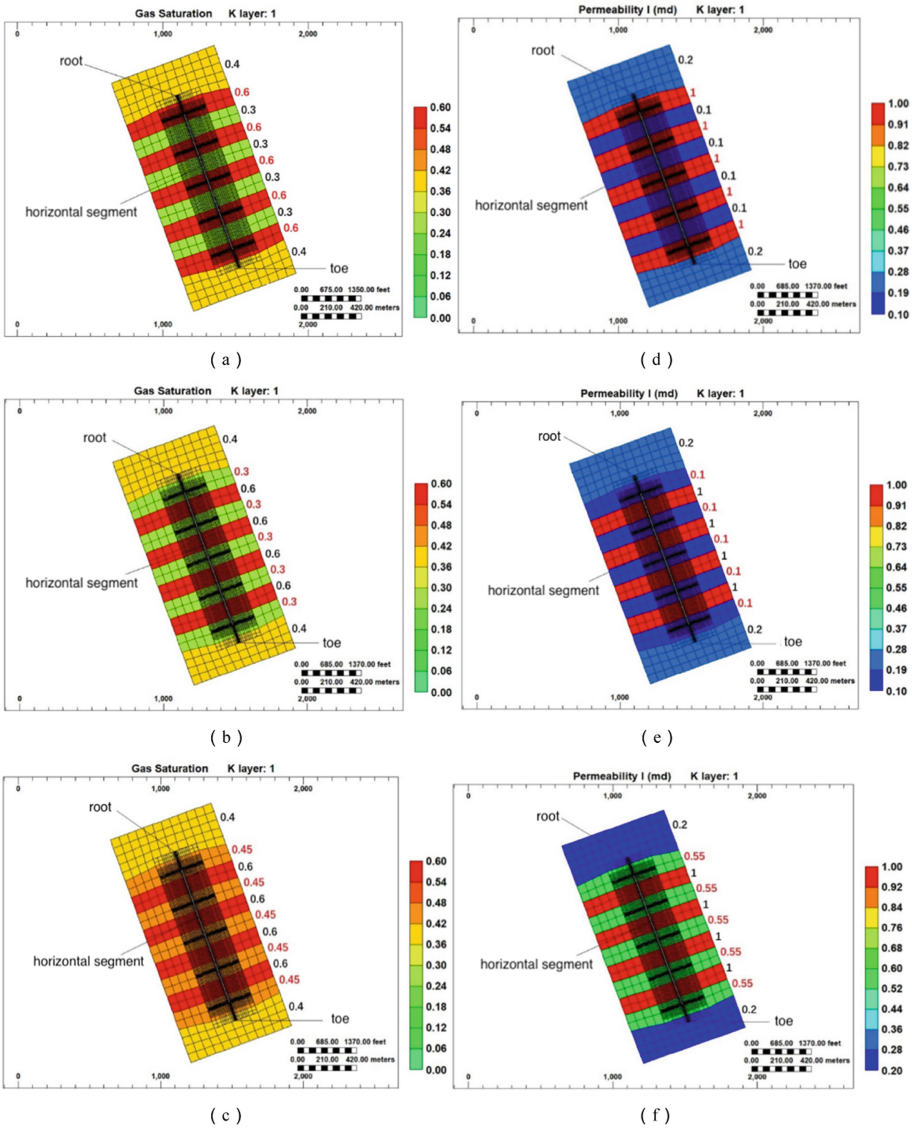


Fig. 4. Schematic diagram of fracture distribution under different reservoir physical properties

Table 4. Cumulative production of gas well with different reservoir properties

Simulation time(year)	Cumulative gas production at high gas saturation $10^4(m^3)$	Cumulative gas production at low gas saturation $10^4(m^3)$	Cumulative gas production at medium gas saturation $10^4(m^3)$	Cumulative gas production at high permeability $10^4(m^3)$	Cumulative gas production at low permeability $10^4(m^3)$	Cumulative gas production at medium permeability $10^4(m^3)$
3	4586.8	1230.5	2329.2	4413.4	2174.6	3855

4.2 The Influence of Natural Fractures on Gas Production

Natural fractures in the reservoir can also affect gas production. Therefore, this section focuses on the influence of natural fractures on gas production at locations with high gas saturation and high permeability. Based on unconventional fracture distribution simulation model a natural fracture model is established, and the influence of the existence of natural fractures at locations with high gas saturation and high permeability on gas production are analyzed. The basic fracture parameters of the model are that the length of the

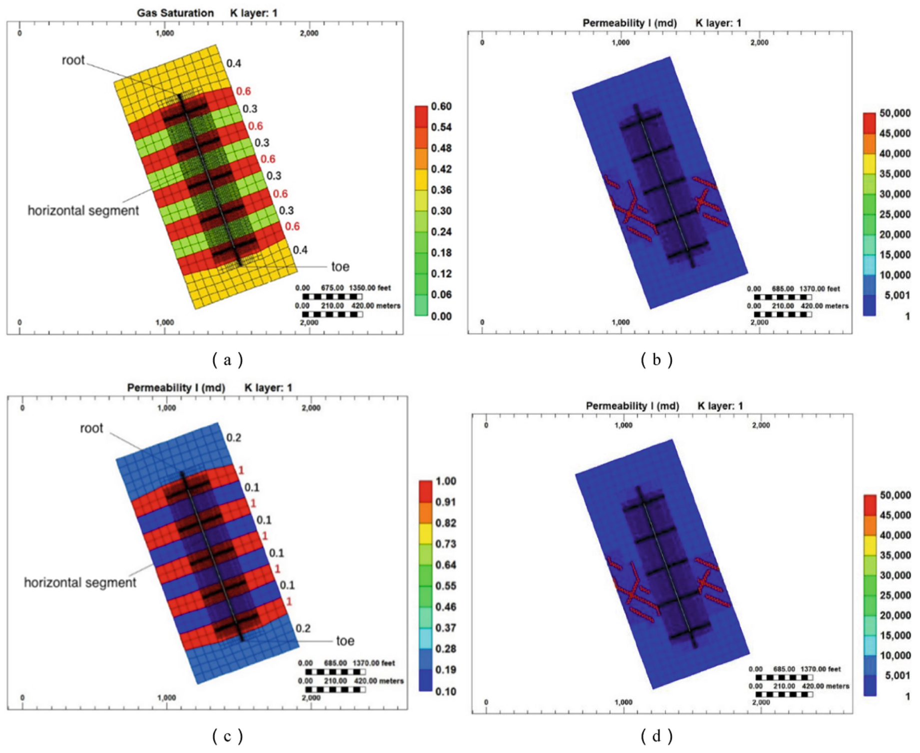


Fig. 5. Diagram of distribution of fractures around natural fractures at different locations

horizontal section is 1000 m, the number of fractures is 5, the fracture half-length is 100 m, the fracture spacing is 200 m, the gas saturation is 0.6, and the permeability is 1.

As shown in Fig. 5, the influence of arranging fractures in four different locations on gas production is analyzed, at no natural fractures in high gas saturation locations (5-a), natural fractures in high gas saturation locations (5-b), no natural fractures in high permeability locations (5-c), natural fractures in high permeability locations (5-d).

Table 5 shows the cumulative gas production after three years of fracturing under the four plans. It can be seen when the fractures are placed at locations with high gas saturation and high permeability and there are natural fractures around artificial fractures, the cumulative gas production is higher. That is to say, the existence of natural fractures will have a positive effect on the cumulative gas production, which will further increase the cumulative gas production. Therefore, fractures should be placed in areas where natural fractures are more developed.

Table 5. Cumulative gas production of gas well with joints around natural fractures

Simulation time(year)	Cumulative gas production without natural fractures in locations with high gas saturation $10^4(m^3)$	Cumulative gas production when natural fractures exist in locations with high gas saturation $10^4(m^3)$	Cumulative gas production without natural fractures in locations with high permeability $10^4(m^3)$	Cumulative gas production when natural fractures exist in locations with high permeability $10^4(m^3)$
3	4586.8	4692.4	4413.4	4462.4

5 Conclusions

(1) Conventional fracture distribution numerical simulation results show that the stimulation influence is better than before when segmented fractures are distributed symmetrically along the central axis of the horizontal wellbore (symmetrical type). When the segmented fracture spacing is small at both ends and large in the middle (the adjacent fractures spacing ratio is greater than 1), the production effect is best when the adjacent fractures spacing ratio is 0.9; When the segmented fracture length is long at both ends and short at the middle (the adjacent fractures length ratio is less than 1), the production effect is best when the adjacent fractures length ratio is 0.8.

(2) Orthogonal test results show that the adjacent fractures length ratio has a greater influence on gas production than the adjacent fractures spacing ratio, and the optimal combination of fracture distribution plan is the symmetrical type fractures with small spacing at both ends and large at the center (the adjacent fractures spacing ratio is 0.7) and symmetrical type fractures with long length at both ends and short at the middle (the adjacent fractures length ratio is 0.9).

(3) Unconventional fracture distribution numerical simulation results show that the cumulative gas production is higher than before when the fractures are laid at locations with high gas saturation and high permeability along the horizontal section, and the existence of natural fractures will further increase the cumulative gas production, fractures should be placed in areas where natural fractures are more developed.

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