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Characterization of Complex Fracture System in Volume Fracturing of Shale Gas Reservoir

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Abstract

After volume fracturing of horizontal wells in shale gas reservoir, an extremely complex fracture system is formed. The space area of the fracture system is the reservoir reconstruction volume of shale gas reservoir. The geometric parameters such as crack length, crack width, crack height, and characteristic parameters such as crack permeability and fracture conductivity proposed for a single crack in conventional fracturing are insufficient to describe and characterize the complex network fracture system after volume fracturing. In this paper, the discrete fracture modeling method is used to establish the volume fracturing network fracture model of horizontal wells in shale gas reservoir by using the random modeling method within the determined reservoir space. The model is random and selective, and can fully provide different forms of volume fracturing fracture expansion, such as conventional fracture morphology, line network model and arbitrarily distributed network fractures. The research results provide a theoretical basis for the development plan and stimulation plan of shale gas reservoir, and have important reference value and significance for other unconventional gas reservoir fracturing.

Keywords

Reservoir Reconstruction Volume, Graphical Combination Method, Boundary Analysis Method, Probability Method, Network Fracture Density

1. Introduction

Shale gas refers to the natural gas in shale reservoirs rich in organic matter, which has been developed and produced in the United States for more than 30 years. In the past decade, shale gas has become an important part of natural gas resources in the United States, driven by technological progress and energy policies, especially the comprehensive application of horizontal wells and large-scale slick water fracturing technology. According to relevant experts' prediction (Einstein et al., 1983), the economically recoverable reserves of shale gas in China are about 26 × 10^{12} m^3, ranking among the top in the world, has enormous economic value and broad market prospects.

Compared with conventional gas reservoirs, shale gas has its particularity in terms of geological accumulation, physical characteristics and development mode, and is difficult to exploit. As the first country in the world to explore and develop shale gas resources, the United States has formed mature exploration and development technologies, such as shale gas reservoir "sweet spot" evaluation technology, long section horizontal well drilling and completion technology, horizontal well staged fracturing and large-scale slick water fracturing technology, and drilling and completion and fracturing "factory operation" technology. Technological progress is the fundamental reason for the successful development of shale gas. More than 30 years of experience in the United States shows that hydraulic fracturing and horizontal well technology are the key development means for the successful development of shale gas, realizing the commercial development and utilization of shale gas, and theoretically and technically proving the possibility of effective development of shale gas resources (Shanley et al., 2004; Xu et al., 2021; Zhu et al., 2022).

The particularity of shale gas reservoir is mainly reflected in: 1) special mode of occurrence and migration: shale gas reservoir has the characteristics of self generation and self storage, and in-situ accumulation; Matrix pores are the main storage space, where adsorbed gas and free gas coexist. Complex seepage mode: 2) Due to the low porosity, low permeability, and natural fracture development characteristics of shale matrix, gas flow in pores follows diffusion laws, Darcy flow in fractures, and desorption phenomenon exists in matrix pores. 3) Extremely complex fracture systems: Monitoring results such as microseisms indicate that the shape of the double wing symmetrical fractures formed by conventional fracturing is different; Complex network fractures are formed after volume fracturing in shale gas reservoir. The above factors make it more difficult to study the stimulation mechanism, seepage mechanism, fracture propagation model and productivity prediction method of fracturing in shale gas reservoir (Dan et al., 2022; Xu et al., 2020; Hlidek & Rieb, 2011).

In terms of numerical simulation of shale gas reservoir, scholars have conducted relevant research, but there are still many key issues that are not clear. In this paper, a volume fracturing productivity prediction model for horizontal wells in shale gas reservoir is established. The discrete fracture model is used to simulate complex fracture morphology, and multiple mass transfer modes such as gas and water two-phase flow, desorption, diffusion migration and Darcy flow are considered; The characterization parameters of volume fracturing fracture system in shale gas reservoir are proposed.

2. Reservoir Renovation Volume

The concept of "volume trouble" in reservoir reconstruction was put forward by M. J. Mayerhofer et al., which originated from the analysis of factors affecting productivity when summarizing the actual production data of Barnett shale gas reservoir. According to the results of microseismic monitoring, the larger the volume of micro earthquake cloud space occupied, that is, the larger the volume of network fracture system, the better the effect after gas well pressure (Kolyukhin & Tveranger, 2014).

There are two main methods for calculating the volume of reservoir reconstruction: one is to divide the complex fracture system of spatial microseismic monitoring (Clark et al., 1999) into several volume blocks, which are reflected in the form of several bands on the plane and longitudinal profiles. The cumulative size of the volume blocks is the volume of the fractured area (Stimulated Reservoir Volume); Second, the spatial micro earthquake cloud is generally expressed in the form of any shape body (Ye et al., 2018), and the volume of any shape body is the effective fracturing volume.

For ease of calculation, the calculation of volume is simplified to the calculation of area, which is the permeability enhancement area (PEA). Solving the problem is the calculation of the area of any enclosed area. The main methods for solving this problem include regular graph combination method, boundary analysis method, and probability method.

3. Network Crack Density

The density of network fractures is a characteristic parameter of complex fracture systems. The density of network fractures refers to the ratio of the volume of all fractures within the reservoir renovation volume to the renovation volume, which is the volume density of fractures. It can also be represented by the surface density and linear density of fractures.

$$\text{Linear density} \quad P_{21} = \frac{L_f}{A_t} \tag{1}$$

$$\text{Surface density} \quad P_{32} = \frac{A_f}{V_t} \tag{2}$$

$$\text{Bulk density} \quad P_{33} = \frac{V_f}{V_t} \tag{3}$$

Among them, and are the linear density, surface density, and volume density of network cracks, respectively; To calculate the total length of cracks on the area surface, m; Is the total volume of the reservoir, m^3; Is the total volume of cracks, m^3; Is the total surface area of the crack, m^2.

4. Complexity of Network Cracks

The formation of complex reticular fractures in shale gas fracturing is controlled by many factors, such as the brittleness of reservoir lithology, the development degree of natural fractures, the size and distribution of crustal stress, etc; Cracks undergo shear failure, dislocation, and sliding, no longer being a single open failure. Due to the influence of the above factors, the morphology of cracks is very complex and difficult to describe with quantitative parameters; Within the volume of reservoir reconstruction, the number of fracture groups and the occurrence (dip angle and strike) of fractures within the group will have a significant impact on the seepage capacity of the fracture system, thereby affecting the productivity of the compressed gas well. Therefore, it is proposed to use the complexity of network cracks, F_c, as one of the characterization parameters for complex crack systems. The larger the F_c value, the more complex the crack system becomes

$$F_c = \frac{\theta}{90} \quad 0 \le \theta \le 90 \quad N = 1 \tag{4}$$

$$F_c = \frac{1}{2} + \frac{\sum_{i}^{N} \left(\alpha_1 + \alpha_i + \cdots + \alpha_N \right)}{N} \quad N > 1 \tag{5}$$

$$\alpha_i = \frac{\theta_i}{90} \quad i = 1, 2, \cdots, N \tag{6}$$

Among them, F_c is defined as the complexity of network cracks, decimal; Number of N crack groups, integer; α_i is the coefficient of crack strike, defined as the ratio of crack strike angle to 90˚; Decimals; θ_i is the strike angle of the crack, defined as the angle between the crack and the horizontal wellbore, in a clockwise direction, in degrees. When there are two or more sets of cracks, it is necessary to meet the condition that at least one set of cracks has a strike angle within the range of 0˚ to 90˚ and 90˚ to 180˚, as shown in **Figure 1**.

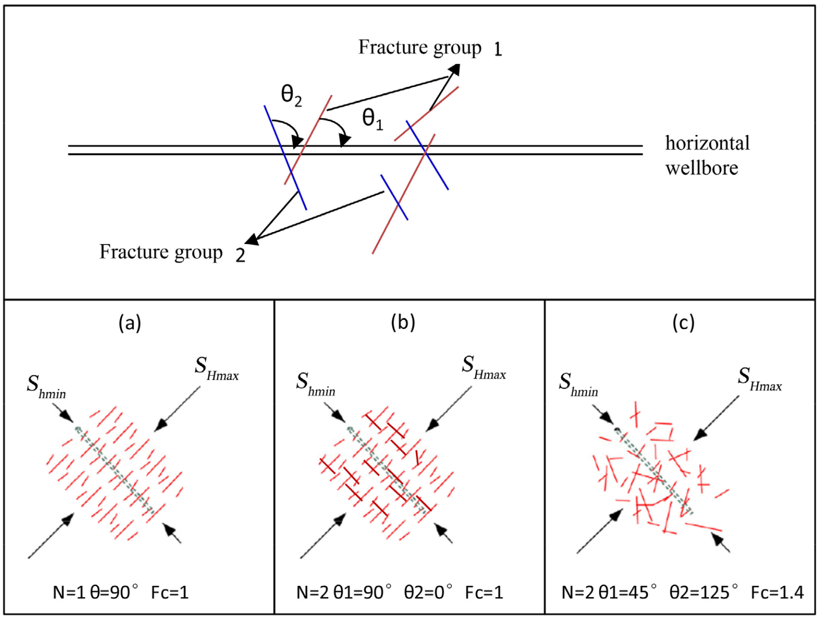

Figure 1. The complexity of fracture network. (a) Single direction; (b) Orthogonal; (c) Complex.

5. Case Study

5.1. Basic Parameters of the Model

Figure 2 shows the results of microseismic monitoring after fracturing of simulated shale gas wells. The simulation assumes that the micro earthquake cloud presents normal distribution in the three-dimensional region. The length, width, and height of the reservoir simulation area are 1200 m, 1200 m, and 100 m respectively, and the volume of the simulation area is 144×10^6 m^3; The scope of fracturing transformation shall be controlled within an area of 400 m in length, 600 m in width, and 100 m in height. The length of the horizontal well section is 1000 m, and the length of the simulated fracturing horizontal well section is 400 m.

5.2. Reservoir Renovation Volume

According to the calculation of elliptical surface and ellipsoidal volume, the area of the fracturing and renovation area is 18.84×10^4 m^2, with a reservoir renovation volume of 18.85×10^6 m^3; Using probability method for statistics, the area of regional renovation is 23.81×10^4 m^2, as shown in Figure 3. After determining the reservoir reconstruction area, the density of micro earthquake cloud data represents the density of fractures. The uniform distribution model is mainly aimed at the sparse network of fractures in reservoirs, or the form of multiple single fractures. Uniform distribution mainly refers to the distribution of fracture positions, strike, and dip angles following a uniform distribution function; In the reservoir model, a single medium model is used for modeling. The random distribution crack model represents a dense network of cracks, and the geometric and distribution parameters of the cracks conform to the random distribution function; In the reservoir model, a dual medium model is used for characterization.

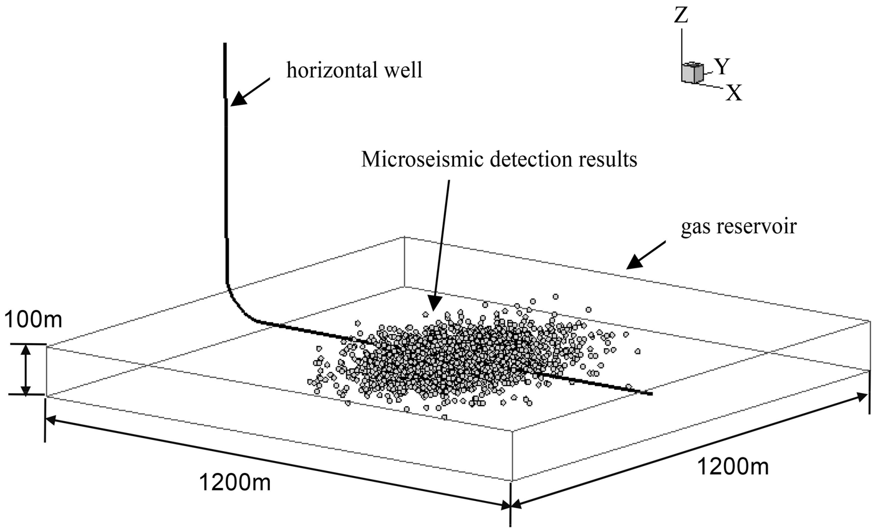

Figure 2. Reservoir model and stimulated reservoir volume.

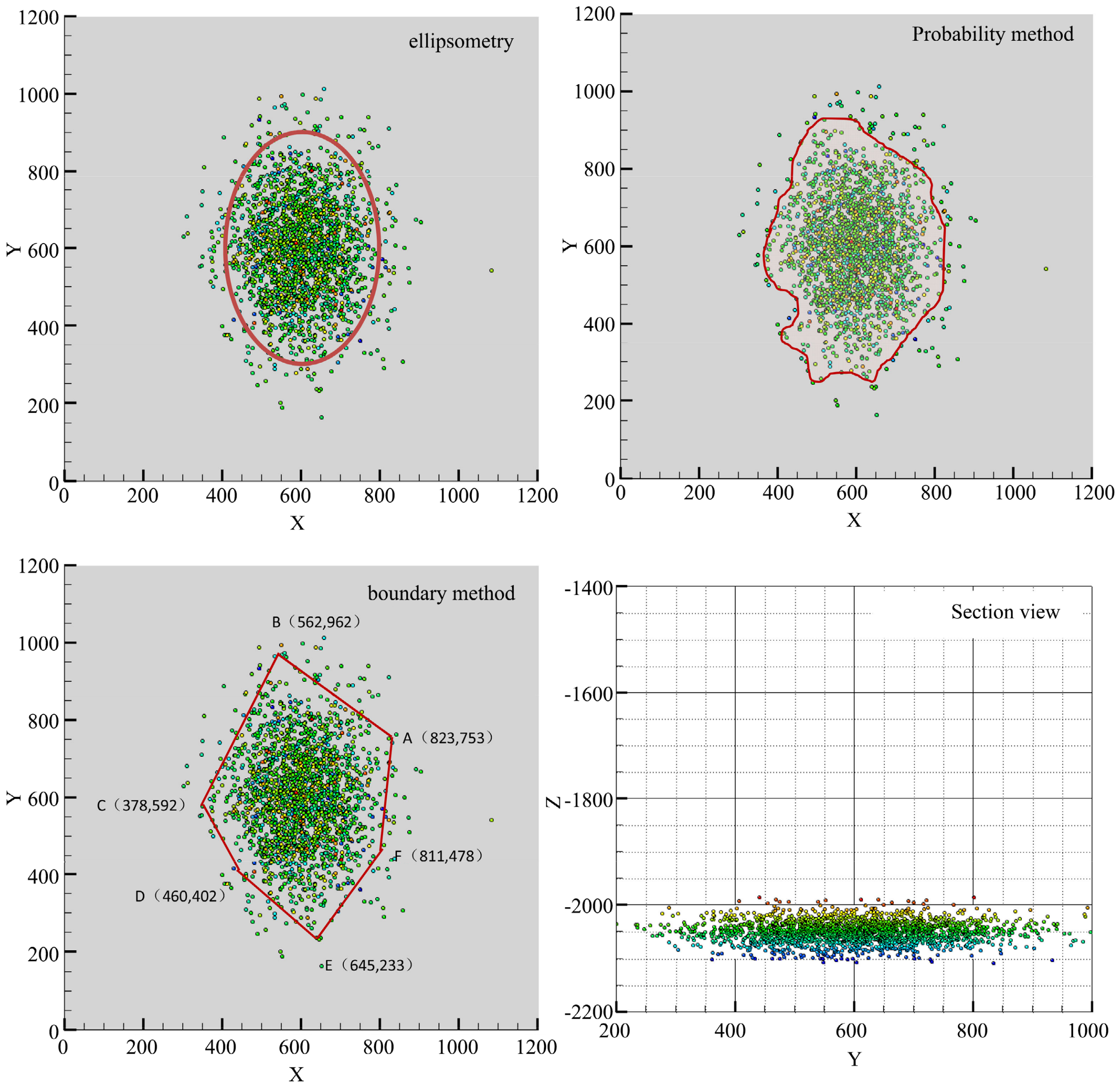

Figure 3. Reservoir stimulated volume and permeability enhanced area.

5.3. Uniformly Distributed Discrete Crack Model

Figure 4 is a schematic diagram of a uniformly distributed crack model. Two distribution types are adopted: network uniform distribution and single fracture uniform distribution, where the single fracture model takes into account the factor of reservoir transformation volume, that is, the overall permeability in the area is increased.

1) The single fracture model has simple parameters and a reservoir reconstruction volume of 18.85×10^6 m^3, the fracture direction is perpendicular to the horizontal well section, the fractures are evenly distributed, with a spacing of 100 m, and the fracture length is 600 m.

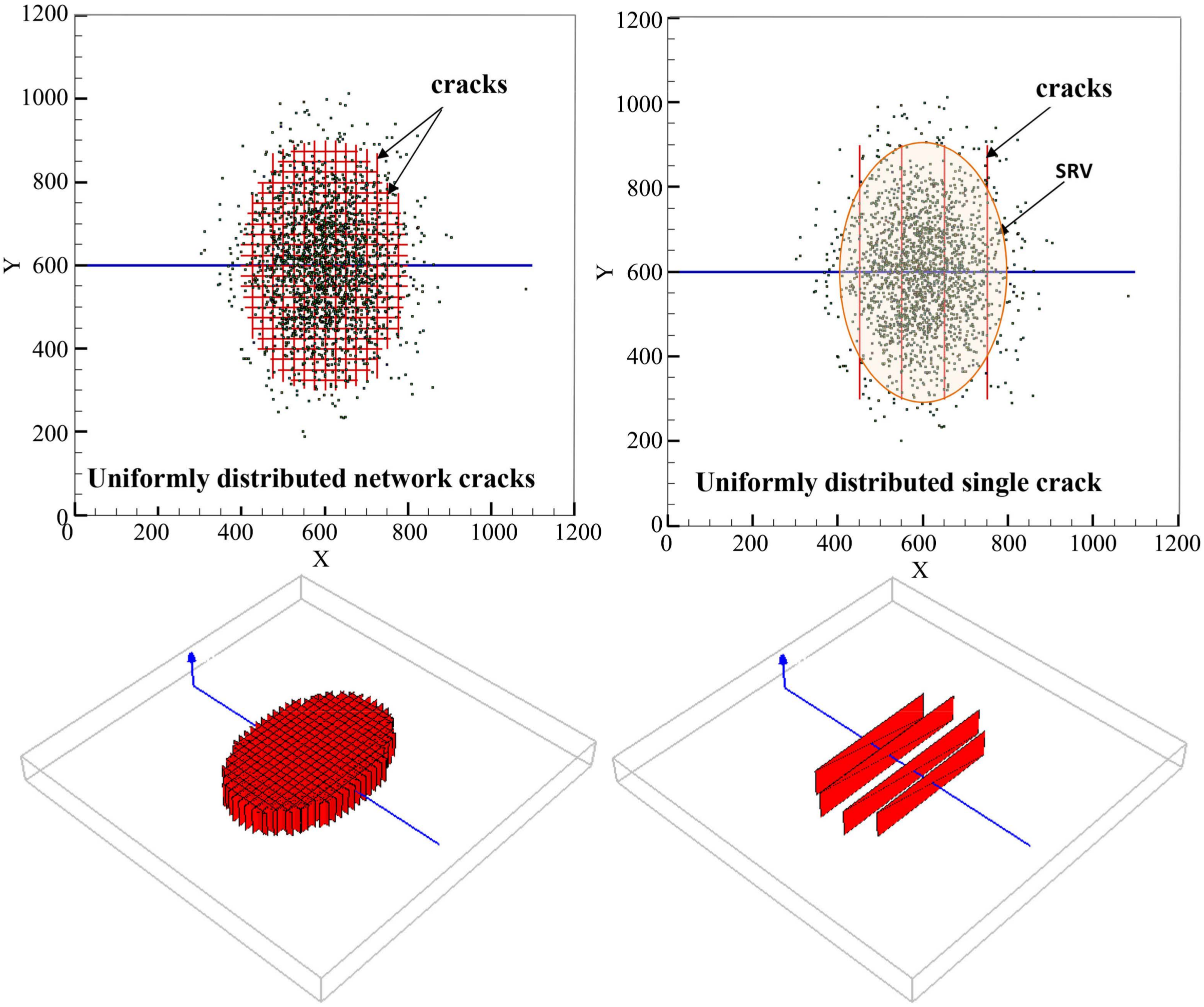

Figure 4. Uniform distribution model.

2) The volume of reservoir transformation with uniformly distributed network fractures is 18.85 × 10^6 m^3, network crack density (linear density) is 0.08/m, and network crack complexity F_c is 1. According to the different occurrence, the fracture group is mainly divided into two groups: perpendicular to the horizontal well section and parallel to the horizontal well section, and its strike/dip angle is divided into 90˚/0˚ and 0˚/0˚; The length of two sets of cracks is 400 m - 600 m (vertical horizontal section) and 150 m - 400 m (parallel horizontal section), respectively. The distribution of crack positions follows a uniform distribution model, and the distance between cracks is 25 m.

5.4. Random Distributed Discrete Crack Model

In the case of high density and complex distribution of network cracks, a random distribution crack model is used for characterization. Applying the Enhancement Beacher model for modeling, all parameters of the crack conform to a random distribution function; In the reservoir model, a dual medium model is used for characterization. Figure 5 is a schematic diagram of a randomly distributed

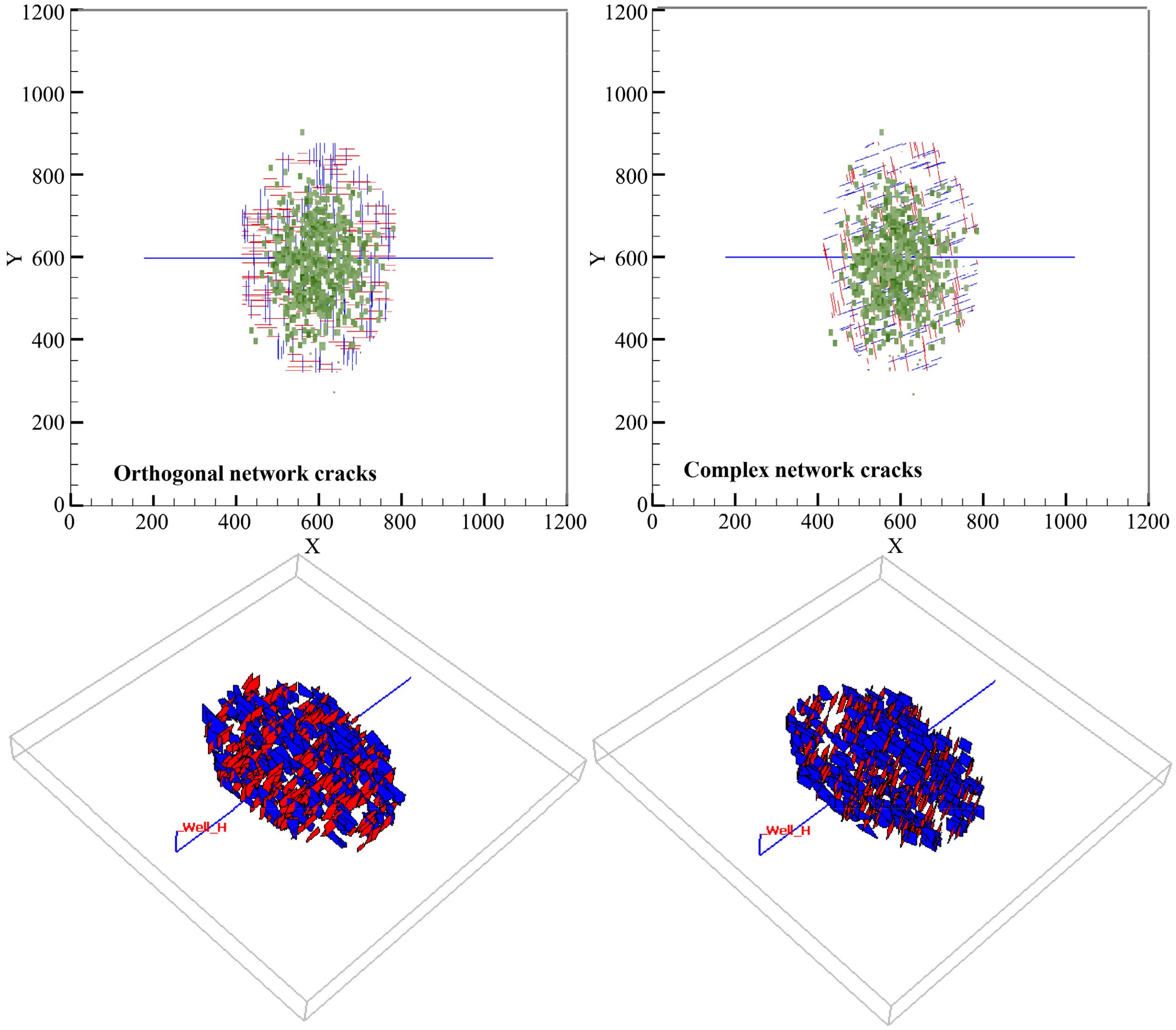

Figure 5. Stochastic distribution model.

crack model. Two distribution types are used: orthogonal network crack model and complex network crack model.

1) The reservoir reconstruction volume of the orthogonal network distributed fracture system is 18.85 × 10^6 m^3, with a mesh crack density (surface density) of 0.05/m and a mesh crack complexity F_c of 1. According to the different occurrence, the fracture group is mainly divided into two groups: perpendicular to the horizontal well section and parallel to the horizontal well section, and its strike/dip angle is divided into 90˚/0˚ and 0˚/0˚; The distribution of cracks is uniform, with a total of 200 cracks; The crack size distribution conforms to the normal distribution function, and its average/deviation = 50 m/25m.

2) The reservoir reconstruction volume of the orthogonal network distributed fracture system is 18.85 × 10^6 m^3, with a mesh crack density (surface density) of 0.05/m and a mesh crack complexity F_c of 1.4. The inclination/strike of the crack

is 85˚/15˚; The distribution of cracks conforms to the normal distribution function, and the parameter is 25/10/0; The crack size distribution conforms to the normal distribution function, and its average/deviation = 50 m/25m.

6. Conclusion

In this paper, the discrete fracture modeling method is used to establish the volume fracturing network fracture model of horizontal wells in shale gas reservoir by using the random modeling method within the determined reservoir space. The model is random and selective, which can provide different forms of volume fracturing fracture expansion, such as conventional fracture morphology, line network model and arbitrarily distributed network fractures. It provides fluid medium model for productivity prediction of shale gas reservoir.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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