Fracture Modeling and Productivity Prediction Technology of Shale Reservoir Based on Multivariate Data

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Abstract. The practice of fracture network fracturing in shale gas layers indicates that the formation of complex fracture networks is directly related to the probability of obtaining a sufficiently large reservoir to effectively rebuild the volume and the ability to obtain high economic benefits. With the continuous deepening of shale gas exploration and development, it is found that the current artificial fractures have slopes, branches and asymmetric distribution. As a result, the production difference between different horizontal wells in the same platform and different fracturing sections of the same horizontal well is obvious. How to optimize the exploration and development plan and promote the economical and effective development of shale gas resources is the most important problem currently facing. The post-evaluation technology of reservoir reconstruction effect has become a key technology. Therefore, it is of great production significance to carry out post-evaluation work by integrating multivariate data. This article takes the SiChuan WeiYuan Shale Gas Demonstration Area as an example, and uses microseismic results and surface seismic data, geology, logging, fracturing and production dynamics data to carry out fracturing fracture modeling and productivity prediction. Provided guidance for fracturing design optimization, development well location, well spacing deployment, and development effectiveness, with good application results.

1. Introduction
In shale gas exploration, there are cases where the adjacent horizontal wells have the same fracturing process and construction parameters, but the production varies greatly. This phenomenon reflects the complexity of the shale gas hydraulic fracturing fracture network. In recent years, geophysicists have paid more and more attention to the comprehensive interpretation of the late stage of fracturing. This requires the integration of microseismic monitoring data and related data, detailed description of fracturing fractures, and comprehensive evaluation.

This article combines the microseismic monitoring data, 3D surface seismic data, geology, well logging, fracturing and production dynamic data in the shale gas block for comprehensive interpretation. In the three-dimensional seismic data work platform disclosed micro fracture identification, interpretation and modeling, the modeling results for the final predicted pressure after production, to guide the development of oil and gas fields, shale gas fracturing design optimization and development Well deployment provides technical support.

2. Fracture Modeling and Productivity Prediction

2.1. Technical Route
After fracturing shale gas reservoirs, the fracture system consists of natural fractures and hydraulic fracturing fractures, and there is strong heterogeneity. The DFN fracture network model is an advanced method for describing fracture systems. By establishing fracture slices of different scales, openings, orientations and shapes, the high-resolution unstructured description of the actual size and distribution of fractures is established. Making geological models more reliable. Use surface seismic, logging, drilling data before fracturing, and microseismic monitoring results during fracturing to perform hierarchical interpretation and modeling of fractures at different scales. Improves the accuracy of the model shale complex fracture, it laid the foundation for the predicted pressure after production, research line shown in Figure 1.

![Research Technology Roadmap](image)

**Figure 1. Research Technology Roadmap**

### 2.2. The Key Technology

#### 2.2.1. Natural fracture identification technology

Natural fractures are a contradiction in reservoir reconstruction. Some natural fractured reservoirs are the largest and most productive in the world. However, in the process of hydraulic sand-fracture fracturing of strata with abundant natural fractures, abnormal high pressure and de-sanding are often encountered, leading to construction failure and even serious accidents. As a monitoring means of hydraulic fracturing, microseismic can make an intuitive evaluation of fracturing effect. A large number of experimental analysis shows that the microseismic event points can identify natural fractures in a certain rule.

- **Waveform Characteristics**: The difference of microseismic event waveform is mainly caused by the difference of event points in space. In terms of surface microseismic monitoring, the distance between the natural fracture event point near the fracture section and the fracture event point is very short, so the waveform of microseismic is basically the same. However, because the energy of natural fracture events is much stronger than that of fracturing events, the amplitude of single track amplitude in natural fractures is higher.

- **Energy Characteristics**: Microseismic event energy is the direct response of rock fracture, which reflects the geophysical characteristics of fracture. The rock fracture caused by hydraulic fracturing results in relatively simple pulse seismic wave, and the complexity of microseismic wave field is mainly affected by medium and propagation speed. The seismic waves triggered by natural fractures are relatively complex, which are more continuous to wave trains, longer propagation duration, and larger average energy than those caused by hydraulic fracturing.

Spatial Characteristics: The microseismic events generated by hydraulic fracturing extend to both sides of the wellbore along with the construction, and the extension direction is basically consistent with the direction of the maximum principal stress in this area. However, the stress response of natural fractures caused by hydraulic fracturing will produce a large number of microseismic events. The
fracture propagation speed is faster than that of hydraulic fracturing, and the spatial distribution is more concentrated. The direction of fracture extension is not significantly related to the direction of the maximum principal stress in this area.

2.2.2. Fracture Interpretation and Modeling
Hydraulic fracturing fracture modeling technology is one of the Characterization Technologies of reservoir reconstruction, which can intuitively show the fracture shape after fracturing, and lay a foundation for evaluating the effect of hydraulic fracturing reconstruction. This study summarizes the distribution of natural fracture events and fracture events in waveform, energy and space, forming the microseismic response characteristics and identification methods of natural fractures. Based on the surface seismic data and the micro seismic monitoring results of hydraulic fracturing, the fracture network model of shale gas reservoir is established by DFN fracture modeling method. Discrete fracture network (DFN) discrete fracture network model describes the fracture system in detail from geometry to seepage characteristics through the fracture pieces of different scales, openings, orientations and shapes distributed in three-dimensional space [1]. In the process of modeling, we can make use of the advantages of multi-disciplinary and multi information data, recognize the fracture from multiple perspectives, and establish the fracture model under multiple constraints, so that the model is relatively reliable.

In the past, the continuous equivalent model was mainly used in the model research of fractured reservoir (Fig. 2(a)). The continuous equivalent model is a kind of highly simplified formation, which is difficult to simulate the fractured reservoir with strong heterogeneity, large scale and poor continuity. Discrete fracture network (DFN) is an advanced description method for fracture system. (Fig. 2(b), Through the establishment of different scale, opening, orientation and shape of fracture pieces, the actual size and distribution of fractures are described in high-resolution unstructured way, which makes the geological model more reliable.

The DFN model has the capability of multi-disciplinary, multi data and multi domain collaborative processing. It can combine outcrop, core, geology, seismic, logging, drilling, production and other multi-scale and multi-scale data together to form a multi condition constrained fracture network model.

2.2.3. Effective Reservoir Reconstruction Volume
The effective reconstruction volume of the reservoir is an important parameter affecting the productivity. In the process of hydraulic fracturing, the natural fracture expands continuously and the brittle rock produces shear slip, forming a fracture network system of natural fracture and artificial fracture, which increases the reservoir reconstruction volume, oil and gas production and recovery rate [2].

![Figure 2. Two Models of Fracture Description](image-url)
Some of the microseismic events in the process of fracturing monitoring are stress response and geological response, so the location of microseismic event point does not completely represent the location of liquid and proppant, so the envelope of microseismic event can not be simply equal to the effective reconstruction volume of reservoir. The purpose of hydraulic fracturing in shale reservoir is to form complex artificial fracture network in reservoir space. When a certain number of natural fractural fractures exist and meet the mechanical conditions of initiation and extension, more secondary branch fractures are formed in the area beyond the artificial main fractures by connecting, opening and extending the natural fractures or weak surfaces of the main fractures, which can expand the oil drainage area and improve the single well production. Therefore, it is necessary to combine the method of fracture simulation to calculate the effective volume of reservoir reconstruction.

2.2.4. Productivity prediction
The production of shale gas mainly depends on staged hydraulic fracturing of horizontal wells to obtain the production. The production capacity of shale gas wells is closely related to geological factors and fracturing parameters. By analyzing the geological characteristics of shale gas reservoirs and using the results of hydraulic fracturing micro seismic monitoring of shale gas, the hydraulic fracturing model is established, and then the dynamic simulation of production is started. The method of finite element analysis and time step calculation is used to comprehensively consider the complex boundary conditions to accurately simulate the flow of fluid in fractures and grid cells. The fracture model can be verified with the production data. If the simulated well test curve is consistent with the actual production well test curve, the seepage capacity of the fracture is considered to be consistent with the actual situation. Then the numerical simulation method is used to solve the dynamic value of productivity, which is of great significance for shale gas production.

3. Application effect

3.1 Study Area Overview
There are abundant shale gas resources in Longmaxi formation of Weiyuan area, Sichuan Basin, The depth of the target layer ranges from 2500 to 3500 meters, and abundant natural fractures. In order to develop shale gas efficiently, horizontal well multi-stage fracturing technology is generally used to increase shale gas production in the region. The thickness of high-quality shale reservoir is 2-6m, the average porosity is 4.61%, the average permeability is $23.63 \times 10^{-3} \mu\text{m}^2$, and the content of brittle minerals is 40% - 65%. In the fracturing process, the fracturing and geological engineers use the microseismic monitoring results to adjust and optimize the fracturing construction parameters in time, and guide the next development work through the post fracturing evaluation in the later stage.

3.2 Fracture Modeling and Productivity Prediction
The first step is establishment of 3D geological model: Based on the surface seismic data of well a, the top bottom interface of the target layer is established, and carry out the natural fracture prediction work, and finally build a 3D geological model;

The second step is to establish large scale fractures: Firstly, according to the high-resolution seismic data and ant tracking technology, a large-scale prediction model of fracture distribution in the study area is established. The location and shape of the model are basically determined, and it does not need to be generated randomly. It only needs to extract the density, dip angle, tendency and length of each fracture, and directly forms the large-scale DFN model of the study area according to the deterministic modeling method.

The third step is the small and medium scale deterministic fracture modeling: According to the microseismic results, the main fracture in the direction of the maximum principal stress and the secondary fracture along the direction of the minimum principal stress are depicted to obtain the deterministic fracture model;
The fourth step is stochastic microfracture modelling: Based on the data of core, logging and outcrop, the parameters of DFN model are established by analyzing the factors such as fracture genesis, strike, inclination, inclination and opening. According to the results of micro seismic monitoring and imaging logging, the hydraulic fracture density volume in the study area is calculated. Then, DFN discrete fracture network technology is used to simulate natural fracture and hydraulic fracture with density volume as constraint, and the discrete fracture network model is formed. Each fracture slice contains attribute information such as fracture porosity, permeability and spacing. Finally, the fracture porosity and fracture permeability model is obtained by using the empirical formula coarsening calculation.

The fifth step is model verification: Model verification includes static verification and dynamic verification. The process of static verification is mainly to compare the DFN fracture model with the microseismic density volume obtained from actual monitoring, which should have a good correlation. The process of dynamic calibration is to iteratively calibrate the early DFN model through the later fracturing simulation and productivity prediction results;

The sixth step is fracturing simulation: In the process of fracturing simulation, the fracturing pump program is mainly used to simulate the liquid entering into the formation through the perforation position to generate pressure fracture, and activate the natural fracture beside the well through the pressure fracture, and support the activated fracture effectively through the proppant to finally form an effective fracture network. The net grid volume of natural fractures activated by hydraulic fracturing can also be calculated through fracture communication, so as to evaluate the effect of reservoir volume modification (Fig. 4);
The seventh step is capacity prediction: In order to verify the fracture model, this paper uses the method of reservoir numerical simulation to evaluate the effective reconstruction volume of the reservoir. After the numerical simulation, by adjusting the parameters of matrix and permeability, the historical fitting method is used to determine the equivalence and practicability of the model for well A. Fracture physical parameters mainly affect the initial gas production. The higher the fracture permeability is, the greater the initial gas production is. The rate of production decline is controlled by matrix permeability, the higher the permeability of matrix, the higher the output in later period, and the slower the production decline. The gas water relative permeability model refers to the simulation study of shale gas water two-phase flow by using Haroalani equation by Bustin et al. When the local formation pressure curve is close to the simulation result, it shows that the established model accords with the real situation, and then it can be used for production dynamic prediction.

It can be seen from the prediction results of well a (Fig. 5) that the production output is consistent with the prediction results, which shows that the method has practical value.

![Figure 5. Cumulative Production Forecast Analysis Chart](image)

4. Conclusion
Based on the microseismic data, the hydraulic fracturing fracture modeling can describe the fracture system of shale gas reservoir, and realize the effective description from the geometric characteristics of fracture system to the seepage behavior of fractured oil and gas reservoir.

Compared with conventional gas reservoirs, the productivity of shale gas reservoirs is relatively complex, so there are many uncertainties in productivity prediction. The adaptability of the method needs further test of production, which is worth further study.

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