

An Equivalent Fracture Modeling Method

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Abstract. 3D fracture network model is built based on discrete fracture surfaces, which are simulated based on fracture length, dip, aperture, height and so on. The interesting area of Wumishan Formation of Renqiu buried hill reservoir is about 57 square kilometer and the thickness of target strata is more than 2000 meters. In addition with great fracture density, the fracture simulation and upscaling of discrete fracture network model of Wumishan Formation are very intense computing. In order to solve this problem, a method of equivalent fracture modeling is proposed. First of all, taking the fracture interpretation data obtained from imaging logging and conventional logging as the basic data, establish the reservoir level model, and then under the constraint of reservoir level model, take fault distance analysis model as the second variable, establish fracture density model by Sequential Gaussian Simulation method. Increasing the width, height and length of fracture, at the same time decreasing its density in order to keep the similar porosity and permeability after upscaling discrete fracture network model. In this way, the fracture model of whole interesting area can be built within an accepted time.

1. Introduction

The discrete fracture network model has been get more and more applications in the research of fractured reservoir[1], this method is the current mainstream technology to describe the fractures, with the advantages of collaborative modeling through fuse data of multidisciplinary, it can integrate outcrop, core, seismic, logging, geology, drilling and production data, so that understanding fractures from different point of view. The discrete fracture network modeling method construct fracture model through simulate the fracture network which composed of fracture slices, the fractures have different shapes, sizes, width and orientation, which realized from the geometry of the fracture system to the flow behavior of real effective detailed description. The technique not only requires the reasonable description of the geometry, size and width of fractures, but also needs to predict the fracture density reasonably, which is the basis and core of fracture modeling[2-3].

The fracture system of Wumishan Formation reservoir in Renqiu buried-hill is very complicated, the key parameters such as length, height, density etc, is difficult to obtain directly through wells data. Tong Hengmao improved the accuracy of prediction results by studying fractures of similar outcrop[4]. Through field observation, the fractures are divided into 4 grades, in which the micro-fractures are usually not reflected in the fracture model because the height is too small. The spacing of the large fractures is about 10 meters, and the density of median fractures is 5-20 stripes per meter, the density of small fractures is 5-50 stripes per meter. Zhang Shujuan classify the fractures into large scale, medium scale and small scale fractures according to the fracture development level, the large and medium scale fractures are described through seismic data, the ant tracking technology is used to



simulate the large and medium scale fractures[5]. Cheng Chao introduced the process of fracture modeling by "ant tracking" technology, and verified the simulation results through imaging logging data. Discrete fracture network modeling technology is usually used to simulate the small scale fractures which can not be recognized by seismic data. The small scale fractures are very developed in Wumishan Formation reservoir in Renqiu buried-hill, which have been proved by outcrop, drilling and production dynamics data[6]. The reservoir area and density of small scale fracture is large, and the strata is very thick, it will takes a lot of computing time to simulate and build the fracture network model for each fractures, the upscaling of fracture model will also very time-consuming. In view of this problem, this paper proposed the equivalent fractures modeling method, increasing the width, height and length of fracture, at the same time decreasing its density, and determine the specific parameter settings through the simulation experiment, by this method, the simulation time is greatly reduced and the porosity and permeability of equivalent model is similar with the original fine model. The method is applied to the small scale fracture modeling of Wumishan Formation reservoir in Renqiu buried-hill, greatly reduced the computation time and meets the needs of the fracture modeling in the study area.

2. The basic principle of equivalent fracture modeling

Discrete fracture network modeling method is a kind of geostatistics modeling method[7], this method produces mainly as a result of many properties such as fractures azimuth, inclination, length, density, width and other information is very difficult to uniquely determined, using deterministic modeling methods are difficult to characterize the statistical characteristics of these parameters, and thus requires to descript and modeling the fractures based on the geostatistics method. In DFN modeling, fractures density is one of the important parameters used to describe the development degree of fracture. Generally, where the fracture density is large, fractures are concentrated and high permeable zones are formed. Dense layers are often formed in where the fracture density is low.

Line density, surface density and volume density is the mainly method to descript fracture density[8]. Line density refers to the number of fractures in the unit length of the direction that perpendicular to the fracture. For example, the fracture density of small and medium scales is generally 5-50 stripes per meter in Renqiu buried-hill reservoir. The fracture network model of the whole reservoir should be established according to the requirements of the reservoir development plan of Wumishan Formation reservoir in Renqiu buried-hill. The DFN modeling technique is adopted for the small scale fractures. The area of the model is 57Km², thickness of strata is more than 2000 meters, at least hundreds of millions of fractures need to be simulated if it is simulate in strict accordance with the fracture density of each fractures, the general computer cannot meet the requirements, and the computation time is not acceptable. To solve this problem, this paper proposed equivalent fractures modeling method, the core idea of this method is the equivalent of multiple fractures to single fracture, its essence is to reduce the fractures density, and it will greatly reduce the time required for fracture modeling. The essence of the porosity and permeability modeling method is a kind of equivalent modeling method, it is impossible to simulate the porosity and permeability for each grain of sand, and also unlikely to direct simulate the porosity and permeability which the logging curves can explain (8 data per meter). Before the simulation, the porosity, permeability and other parameters are equivalent to the simulated grid by using the logging upscaling method, and then the grid is simulated.

The main input parameters of reservoir simulation are porosity and permeability model, rather than directly using the fracture network model. The equivalent fracture modeling method can reduce the density of fractures, and the simulated fracture porosity and permeability will also decrease. The porosity and permeability of single fracture are mainly related to the length, height, width and density of fractures. Formulas (1) and (2) are theoretical formulas for the calculation of porosity and permeability of single fracture[9],

$$\phi_f = \frac{e \cdot \lambda \cdot l}{D \cdot V_T} \quad (1)$$

$$K_f = \frac{e_1^3}{12D_1} \cos \alpha + \frac{e_2^3}{12D_2} \cos \beta + \dots \quad (2)$$

Φ_f is fracture porosity, K_f is fracture permeability, V_T is rock volume, λ is fracture length, l is fractures height, e is fractures width, D is fractures spacing, α and β is the angle between fluid pressure gradient axis and the fractures. From these two formulas, it can be seen that the porosity of the single set of fractures is mainly related to the length, height, width and density of fractures, and the permeability is mainly related to the fracture width and density. The equivalent fracture method proposed in this paper is actually to increase the width, height and length of fracture, at the same time decreasing its density in order to keep the similar porosity and permeability after upscaling discrete fracture network model.

3. Case study

Renqiu buried hill reservoir is located in the north of the Raoyang Sag in the Jizhong Depression. It is a large buried hill reservoir which composed of the carbonate strata of the Middle Proterozoic Wumishan Formation of the Jixian System, belonging to the fractured, bottom water, massive, low saturated reservoir[10]. Renqiu buried hill is divided into 10 oil groups, initially with a unified oil and water interface and a unified pressure system. This buried hill reservoir, being half-anticlines cut by several normal faulting, and the palaeotopography was steep in the west and north, low in the west and south. The formation, showing the characteristics of south old and north new, top surface morphology was in northeast direction, and the structure pattern was composed by four fault terraces and five hills. The buried fractures and faults are very developed. Due to the influence of multi-stage tectonic movement, the faults at different levels are overlapped with each other, and then the faults are further complicated. The faults are mainly developed in the northwest, north-east, north-north-east and nearly east-westward.

3.1. Fracture intensity model

According to the results of fractured logging, the reservoirs in the study area can be classified into four types: fracture development layers, with high porosity, indicated by the code "1"; fractures are relatively developed, with the code "2"; micro-fracture development, with the code "3"; other non-reservoir layer, that is, the fracture is not developed, with the code "0" to represent. In the process of fracture modeling, it is necessary to determine the probability distribution curve of each layer in the vertical direction first, as a constrained condition of the simulation process. By calculating and fitting the variogram of different levels of reservoirs, the author established the reservoir level model by sequential indication simulation method (Figure 1), the fractures are well developed. Through the outcrop and field geological observation, it is concluded that the frequency of tectonic fractures is related to the tectonic sites and faults, the closer to the faults, the more intensive the fractures are, and the fracture density decreases with the increase of the fault distance. In order to predict the density of fractures more rationally, this paper constructs the fault distance constraint model based on the fault distribution model, and predicts the fractures density as the auxiliary variable (Figure 2).

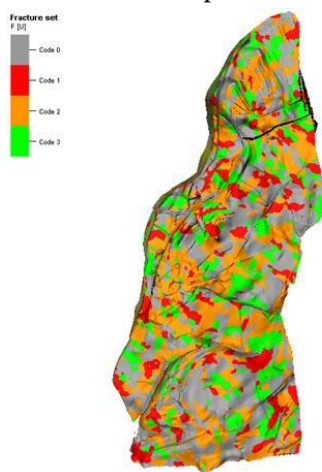


Figure 1. Reservoir level model.

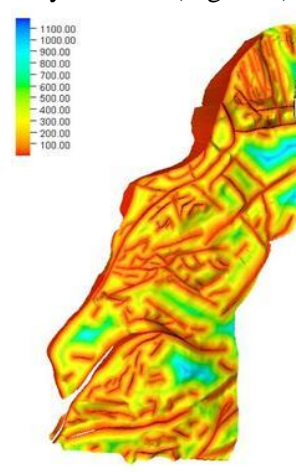


Figure 2. Fault distance analysis model.

Under the constraint of the reservoir level model, the fracture distance model is used as the second variable. Assigned the fracture density through the reservoir level, and then established the fracture intensity model by the sequential Gaussian simulation method (Figure 3).

3.2. Determination of simulation parameters for equivalent fracture modeling

In order to determine the relevant parameters of the equivalent fracture modeling and the effectiveness of the method, a small work area was selected to carry out the simulation test. The test area is 5Km², and the formation thickness is 400m. The structure is relatively simple. Taking the fracture density of 2 stripes per meter as an example, reduced it to 1 stripes per meter, 0.5 stripes per meter, 0.1 stripes per meter, 0.01 stripes per meter, establishing the discrete fracture network model, fractures porosity and permeability model, and then statistics calculating time. The statistical results are shown in Table 1.

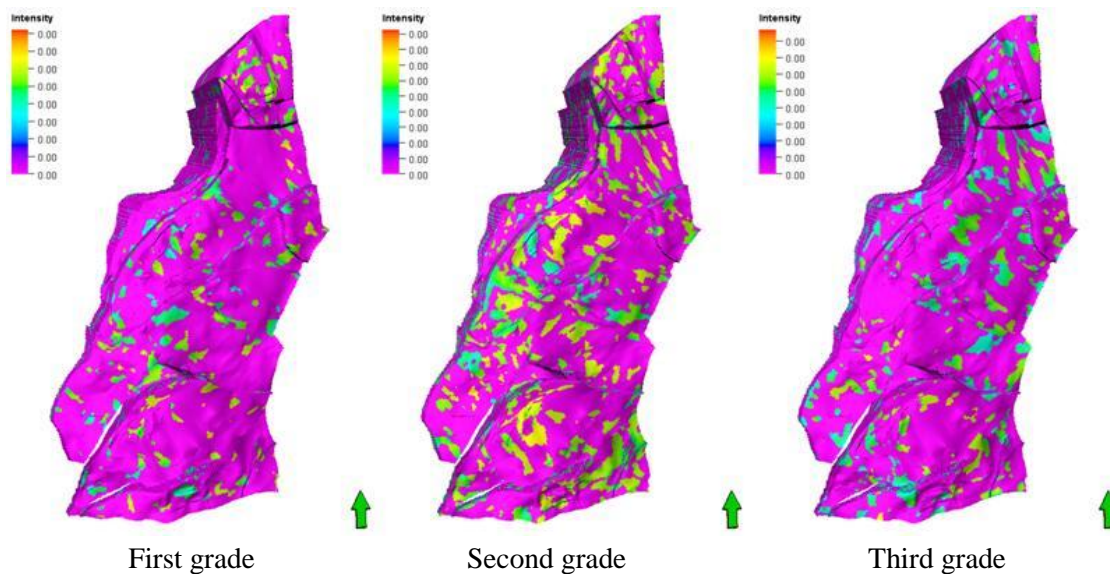


Figure 3. Fracture intensity model.

Table 1. Parameter settings of fracture modeling.

Mean fracture density (stripes per meter)	0.01	0.1	0.5	1	2
Fracture quantity	4423	150760	1075110	2511160	8861130
Mean fracture width (m)	0.003	0.0018	0.0008	0.0005	0.0004
Mean fracture length (m)	300	200	100	80	50
Mean fracture height (m)	75	50	20	10	8
Mean fracture porosity (%)	0.15	0.13	0.15	0.14	0.16
Mean fracture permeability (md)	43132	43547	42924	44511	42676
Time (min)	0.08	9	28	59	129
Computer configuration	Memory 16GB CPU: Intel(r) Core(TM)i7-4790 CPU@3.6GHz				

According to the results of the statistics in the table, it can be seen that by increasing the width, height and length of fracture, at the same time decreasing its density, can keep the similar porosity and permeability after upscaling discrete fracture network model. The area of the reservoir model of Wumishan Formation reservoir in Renqiu buried-hill is 57Km², the thickness of the formation is more than 2200 meters, and the average fractures density is about 2 Stripes per meter. Through simple conversion, we need to simulate more than 500 million fractures, and one simulation will takes for more than 120 hours. Due to memory constraints and other reasons in the actual simulations, the calculation time is not a simple linear increase, and then considering the stochastic simulation need to simulate multiple realizations, the traditional modeling method cannot meet the needs of practical

work. By using the equivalent fractures modeling method, the calculation and upscaling time of the fracture are reduced by about two orders of magnitude, which satisfies the needs of the actual research work and ensures the consistency of the key geological parameters before and after upscaling.

Previous studies have shown that the density of the first grade fractures in the study area is less than 0.1 stripes per meter, the fractures density of the second grade fractures is about 0.5 stripes per meter, and the fractures density of the third grade fractures is between 0.5-10 stripes per meter. Petrel provides three kinds of fracture density, namely volume density, line density and areal density.

In the study area, the length of the first grade fractures is between 10-100m, the length of the second grade fractures is between 1-10m, the length of the third grade fractures is between 0.5-1m, and a single grid volume of the model is $50 * 50 * 2\text{m}$.

The fracture density of model is calculated according to the above formula:

$$\frac{\text{Length of single fracture} * \text{Empirical density of fracture} * \text{Length of single grid}}{\text{Volume of single grid}} \quad (3)$$

Table 2 is the fracture characterization parameter settings before and after the equivalent. The density of first, second and third grade fractures are reduced, and the length, height and width of fractures are increased.

Table 2. Fracture characterization parameter settings before and after the equivalent

	Density(stripes per meter)		Length(m)		Height(m)		Width(m)	
	BEF	AFT	BEF	AFT	BEF	AFT	BEF	AFT
Fracture grade 1	0.01	0.001	10	200	2	20	0.001	0.008
Fracture grade 2	0.02	0.002	4	80	1	10	0.0005	0.004
Fracture grade 3	0.005	0.0005	0.5	10	0.1	1	0.0001	0.001

3.3. Discrete fracture network model

This paper uses the popular ant tracking technique to simulate the large-scale and medium scale fractures that can be identified by seismic data[11]. Firstly, the original seismic attribute data is processed by structure smoothing, chaos, variance etc, to enhance the discontinuity of seismic data in the space[12], then based on the analysis of fracture characteristics in study area, tracking the seismic attribute through the reasonable parameter settings of ant tracking, and then construct the ant attribute model. Finally, the large scale discrete fracture distribution model is established by deterministic modeling method. For small scale fractures, take the fracture intensity model as constraints of the enrichment degree of fracture development, using discrete fracture network modeling module of Petrel software[13], simulate the small scale fractures by equivalent fractures modeling method proposed in this paper. Setting different fracture extension length, fracture height, fracture width and other fracture parameters for different grades of fracture, simulate fractures in different grades and different layers respectively. At the end of the simulation of fractures at various scales, the whole fractures model is constructed by a fracture network which composed of various fracture slices.

3.4. Fracture property model

Based on the fracture network model, the fracture network model is upscaled into fracture porosity and permeability model by using Petrel software. According to the actual data in the study area, using the Oda method, with a total area of fractures in single grid and different parameters of fractures as a basis to estimate the porosity and permeability, established the fracture porosity model and permeability model in three directions, which laid the foundation for the reservoir simulation.

4. Conclusions

- In order to solve the problem that when the fracture intensity is great, generate a fracture network model for a large area will require long time, propose a method of equivalent

fracture modeling. Equivalent multiple fractures to one fracture, the essence of the method is to reduce the overall density of fractures, increase the length, height, and width of the single fracture, it will greatly reduce the time required for fracture modeling, while ensuring pore and permeability simulation result is reasonable.

- b) Setting different fracture extension length, fracture height, fracture width and other fracture parameters for different grades of fracture, simulate fractures in different grades and different layers respectively under the constraints of the fracture intensity property, described the distribution characteristics of fractures in study area finely.
- c) Combined equivalent fracture modeling method with the ant tracking technology, established large-scale, medium-scale and small-scale discrete fracture network model for W1-W10 oil group in carbonate reservoir of Renqiu buried hills, The model described the geometry and the flow behavior of the fracture system in detail, providing basic support for late numerical simulation and remaining oil distribution study.

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