Exploration of 3D Simulation of Geothermal Field Based on Geophysics Exploration — Geothermal Geological Modeling

Yongshan Zhu¹, Ning Zhao², Xiaoli Mi¹, Mengya Wang¹, Qing Li¹, Yao Yao¹, Zhuohan Wei¹

¹Comprehensive geophysical and geochemical exploration Office of Dongfang geophysical company, Zhuozhou, Hebei,
²School of physics and electronic information, Henan Polytechnic University, 454000, Jiaozuo Henan

Abstract. This paper introduces a method of three-dimensional simulation of geothermal field in the study area by using the finite element method after the geothermal geological modeling based on geophysical exploration. First of all, through geophysical exploration, the three-dimensional geological model of the study area is established, and the thermal conductivity of different strata and lithology of the geological model is assigned, then the three-dimensional geothermal geological model is established; Second, set initial conditions such as surface temperature and heat source for the geothermal geological model, and then use mesh adaptive technology to perform automatic mesh division; Finally, three-dimensional geothermal field was obtained by parallel calculation in three-dimensional simulation space. This method has been applied in geothermal research in Shuguang area of Liaohe Oilfield, and the simulation results are very well.

1. Introduction
As a kind of recognized clean energy, the development and utilization of geothermal resource are paid more and more attention, and it is also the key content of China's 13th five year plan. Prospects for development and utilization of geothermal resources in the northern oil areas is very well [1]. It not only provides clean energy for people's daily life, but also can play an energy-saving and emission-reducing role in oilfield crude oil pipeline transportation and oilfield production. It is of great practical significance to improve environmental pollution, control "haze" and optimize regional energy structure in the northern region of China[2]. The research on the geothermal field with better geothermal resource conditions is helpful for the scientific and rational development of geothermal resources, and it also has great significance for the sustainable development and utilization of geothermal resources.

The geothermal geological model of the study area is established based on the results of geophysical exploration, and then the geothermal field in the study area is numerically simulated and calculated by using the adaptive finite element method[3], so as to obtain the distribution characteristics of the temperature field in the target area and provide an important basis for the later geothermal field scientific and standardized drilling.

2. Overview of 3D geothermal field simulation
In this paper, the continuous temperature field in the calculation area is discretized into a finite number of temperature points by using the finite element method, and then the temperature values of these
temperature points under the given conditions are calculated, so as to approximately represent the
temperature field to be solved. When the distance between discrete temperature points is smaller, the
number of discrete points is larger, so that the obtained result is closer to the real temperature field.
However, when the number of points is more, the calculation time will be longer. Therefore, in the
specific calculation, the adaptive mesh generation technology is used to deal with the actual grid error,
and the number of discrete temperature points will be reduced as far as possible when the accuracy
requirements are met. At the same time, the load balancing technology is used to improve the
calculation efficiency, as shown in Figure 1.

The heat transfer equation can be solved by analytical method or numerical simulation method. In
the geothermal field, it is very difficult to solution formula Analytical solutions due to the complex
geological conditions inside the crust, various thermophysical parameters of the rocks are different,
and the boundaries of the calculation area will show various irregular shapes due to different
geomorphology and topography. Corresponding analytic solutions can be obtained only in some
simpler and special cases. Therefore, numerical methods are often used to solve the complex problems.

This work uses the finite element method as a numerical simulation method to achieve three-
dimensional numerical simulation of the geothermal temperature field. The finite element method was
first developed in the field of elasticity in the 1950s. Its main advantage is that it is suitable for the
area with complex distribution of physical parameters. The finite element method is based on the
differential equation and the weighted residual method to derive the linear algebraic equation of node
temperature, which has the advantages of high accuracy and strong adaptability. In this paper, the
finite element method is used to realize the three-dimensional numerical simulation of geothermal
temperature field.

![Figure 1. Function diagram of 3D geothermal field simulation](image)

3. Geothermal field simulation method Steps
The 3D geothermal field simulation is based on the geophysical data. Through the interpretation of
faults, strata, structures and lithology, the comprehensive geological interpretation profile is obtained.
Basis on that, the 3D geothermal geological model of the work area is established, and then the 3D
adaptive finite element geothermal field simulation software is used to carry out the 3D geothermal
field numerical simulation. The 3D geothermal field numerical simulation process is as follows:

The first step is to make a comprehensive geological interpretation of the resistivity profile
combined with the drilling data, and to find out the geological characteristics of the fracture, stratum,
structure and lithology in the study area, then three-dimensional geological model can be established
in the study area(Areas without 3D geophysical data are interpolated by 2D sections to build 3D
models);

Step 2, fill the stratum in the 3D geological model established in step 1 with physical property
information such as thermal conductivity and porosity to establish a 3D geothermal parameter model;

Step 3, set the initial conditions such as the surface temperature and heat source of the geothermal
geological model;
Step 4, the 3D geothermal field was calculated by 3D adaptive finite element simulation software.

4. Example analysis

4.1. Magnetotelluric exploration

In Shuguang Xinglongtai area of the oilfield, five lines for magnetotelluric sounding exploration are deployed, with NE line orientation, 200m point distance and 3km line distance. See Figure 2 for the location of the line.

4.2. Magnetotelluric Data Processing

Five lines were comprehensively processed to form a resistivity inversion profile, as shown in Figure 3. It can be seen from the figure that the vertical resistivity of this area is characterized by the gradual increase from shallow to deep, which is generally characterized by shallow low resistance - middle transition - deep high resistance; horizontally, it is generally shown that the shallow low resistance in the northwest and Southeast sections is relatively thin, and the middle section is relatively thick, and the buried hill in the low resistance thin area is relatively shallow, otherwise it is relatively deep.

4.3. Comprehensive interpretation of geophysical data

Taking the magnetotelluric profile as the basic framework, combined with the previous geophysical data such as gravity and magnetic method, the profile is comprehensively interpreted, as shown in Figure 4. The Quaternary and Neogene Guantao formation are developed in the shallow layer, mainly sandstone and mudstone, which are thick in the northwest and thin in the southeast, with a thickness range of 600 m ~ 1200 m; The Paleogene Dongying Formation to Shahejie Formation are in the rifting strata, mainly sandstone and mudstone. The thickness varies greatly. The thinnest part of the Shuguang buried mountain area in the northwest is less than 100 m and the northwest end of 05 survey line is missing, and the thickness of the formation increases rapidly in southeast direction, with the thickest up to about 4000 m; Generally, the thickness of Fangshenpao formation of Paleogene is less than 100m, which is a set of basalt, and the southeast section is basically missing; The thickness of Mesozoic is in the range of 0-1000 m, the two ends of lines 02, 03 and 04 are thick, the middle part is thin or missing, and the main lithology is volcanic rock, sand and mudstone: The basement of Shuguang buried hill area and Xinglongtai buried hill area is obviously different. The Proterozoic basement is mainly distributed in Shuguang buried hill area in the northwest section of the survey line, and the main lithology is dolomite, limestone, etc. the Mesozoic in Xinglongtai buried hill area is not integrated on the Archean, and the main lithology of Archean is granite gneiss.
Through comprehensive interpretation of the magnetotelluric and gravitational and magnetic data in this area, the three-dimensional geological model of the work area is basically established, as shown in Figure 4.

Figure 4. Comprehensive geological interpretation of Magnetotelluric Inversion profile

4.4. Geothermal geological modeling
Based on the geological modeling, the thermal conductivity is assigned based on the main lithological characteristics of each set of rock layers, thereby establishing a three-dimensional data volume of thermal conductivity in the work area. See Table 1 for details of thermal conductivity values for different lithologies.

4.5. Adaptive mesh generation
After establishing a three-dimensional geothermal geological model of the work area, the data is first spatially adaptively meshed (Figure 5). Its characteristics are that the cells are refined in areas with large changes in thermophysical properties, and appropriately reducing the number of cells in areas with the same or small changes in thermal physical properties, so as to greatly improve the simulation speed while ensuring the accuracy of three-dimensional simulation.

Table 1. List of common rock density and thermal conductivity

| Rock names                          | density (kg/cm³) | Thermal conductivity [W/(m·°C)] |
|-------------------------------------|-----------------|---------------------------------|
| Granite                             | 2700            | 2.721                           |
| limestone                           | 2700            | 2.010                           |
| Sandstone                           | 2600            | 2.596                           |
| Wet shale                           | —               | 1.4~2.4                         |
| Dry shale                           | —               | 0.64~0.86                       |
| Calcareous sandstone (water content 43%) | 1670           | 0.712                           |
| Dry quartz sandstone (medium fine)  | 1650            | 0.264                           |
| Quartz sandstone (moisture content 8.3%) | 1750           | 0.586                           |
Sandy clay (moisture content 15%)  & 1780 & 0.921 \\
Sandstone (glutenite) & — & 0.77 \\

| Material       | Moisture Content | Conductivity |
|-----------------|------------------|--------------|
| Sandy clay     | 15%              | 1780         |
| Sandstone      | —                | 0.77         |

**Figure 5.** Adaptive grid generation of geothermal geological model

**Figure 6.** Three dimensional temperature field simulation results in Shuguang Xinglongtai area

### 4.6. Geothermal field simulation calculation

The three-dimensional data of the spatial distribution of geotemperature field is formed by the three-dimensional adaptive finite element simulation. Figure 6 and 7 show the three-dimensional data volume and the two-dimensional slice of the geothermal field in the Shuguang-Xinglongtai area, respectively. It can be seen from the figure that there are two rows of high ground temperature anomaly areas in Shuguang Xinglongtai area, which are the high temperature anomaly area of Shuguang buried hill in the northwest and the high temperature anomaly area of Xinglongtai buried hill in the southeast. The high temperature anomaly is more obvious below the burial depth of 2000m. In Shuguang area, the isoline of geotemperature rises up more obviously, which is the area with the highest geotemperature gradient in the whole survey area. As a whole, the distribution of temperature field is closely related to the fluctuation of the top of buried hill, which is due to the higher thermal conductivity of limestone and granitic gneiss in the buried hill area, and the conduction of heat flow from the deep to the shallow layer to the high thermal conductivity rock distribution area.
5. Conclusions
This work explored the establishment of a geological model of the work area based on the results of comprehensive geophysical interpretation of geophysical exploration. Based on this, a geothermal geological model was established in combination with the characteristics of formation thermal conductivity. The final numerical simulation results are in good agreement with the actual geothermal field distribution. The development and utilization of geothermal resources has certain guiding significance.

6. Acknowledgements
Thanks to Dr. Zhao Ning, senior engineer Mi Xiaoli and other colleagues for their guidance and help; Thank you for the support of CNPC science and technology project "Research on Key Technologies of geothermal exploration (No.: 2019t-009-003)".

References
[1] Duan Z, Pang Z and Yang F 2013 Features of Coal-bearing Strata Rock Thermal Conductivity and Influence on Heat Hazard in North China[J] Coal Science and Technology 41(8) 15-17
[2] Li G 2016 Geological Characteristics of Xinglongtal Area in Western Depression of Liaohe Depression of Bohai Bay Basin[J] China’s Manganese Industry 34(6) 50-52
[3] Chen S, Huang R 1995 A numerical simulation of geotemperature field of a deeply euried tunnel[J] journal of geological hazards and environment preservation 6(2) 30-36