Evaluation Method of Regional Geothermal Resources - A Case Study of Yingzhou District, Fuyang, Anhui Province

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Abstract: Geothermal is a kind of renewable, clean and environmental protection new energy. In the process of exploiting geothermal energy by groundwater heat pump (GWHP) system, the regional geothermal water resource is the basis of the system running continuously. In this paper, taking Yingzhou District, Fuyang, Anhui Province as an example, a conceptual model of thermal reservoir is proposed according to the general situation of regional hydrogeology, considers the main thermal storage parameters, and combines with the pumping test data of a geothermal well of the project to calculate the exploitation quantity of single well geothermal water. Then, the regional geothermal reserves, recoverable geothermal water and total heat are evaluated. The results show that the total recoverable geothermal water resources of the Neogene Guantao formation and the Paleogene Jieshou formation in the project area are 9.093 million m³/a, and the recoverable geothermal resources amount is 9.6795×10¹⁶ J, which reaches the medium-low temperature and medium-sized geothermal field scale. Furthermore, the recoverable resources of geothermal water in the reservoir obtained by the method of average well distribution satisfy the condition of water-heat balance, which will be applied to the evaluation of regional geothermal resource exploitation.

1. Introduction
In recent decades, with the rapid development of China's economy and the acceleration of urbanization, the population and residential area growth quickly, the building energy consumption also increases year by year. At present, the level of building energy consumption per unit area in China is basically the same as that in the United States in the 1960s and Japan in the 1970s, and is about 50% ~ 60% of that today [1]. The concept of energy conservation and emission reduction is being widely recognized in China and all over the world.

Geothermal energy is a new kind of clean and renewable energy, which is growing rapidly at the rate of about 10% every year in China [2]. As one of the abundant and stable new energy sources in the world [3], geothermal energy has been widely used in the fields of power generation, building heating and cooling [4-6]. In the face of the increasing building energy consumption and the corresponding environmental pollution problems, the groundwater heat pump (GWHP) system can reduce the pollutant emissions by more than 40% compared with the ordinary air conditioning, as opposed to the electric heating system, the reduction ratio can be as high as 70% [7]. Therefore, GWHP technology has been widely used and developed in many countries in recent years.
The application of geothermal energy technology such as GWHP is based on groundwater, which uses water as medium for energy conversion in various forms [8-11]. However, most of the achievements have been focused on the numerical simulation of groundwater dynamic field, temperature field and water-heat coupling [12-15], but there are few studies on the method of regional geothermal water resources evaluation and calculation. Taking Yingzhou District, Fuyang, Anhui Province, China as an example, this paper calculates the regional geothermal energy reserves, recoverable geothermal water and total heat through the conceptual model of thermal reservoir and the parameters of thermal reservoir, then the scale and energy utilization of regional geothermal field are evaluated, which can provide reference for similar project evaluation.

2. Materials and Methods

2.1 Overview of the study area
Fuyang city in Anhui province, the southern part of the North China Plain and the western part of the Huaibei Plain, is located in the middle latitude of East China. Yingzhou District is one of the three municipal districts in Fuyang with a well-developed surface water system and numerous rivers, mainly flowing through the urban areas of Ying river, Quanhe, Cih, Cihuai, and Jihe rivers. The regional strata belong to the north China stratigraphic and the Huai river stratigraphic region, where the faults are well developed and rich in geothermal resources.

2.2 Conceptual model of heat storage
Geothermal water in the project area is mainly found in the lower part of the Neogene Guantao formation (below 898.0m) and the strata of Jieshou formation in the Paleogene. The upper part of Guantao formation is fine sandstone with gravel and coarse sandstone, and the lower part is mudstone and argillaceous siltstone interbedded with argillaceous fine sandstone, with a thickness of 606.7m. The Paleogene Jieshou formation is composed of silty mudstone interbedded with fine sandstone and argillaceous siltstone, sandwiched with fine-grained feldspar sandstone. In these two sets of formations, the sand layer is mostly loose, with good water storage performance and stable distribution in the region. Based on the analysis of the characteristics of strata, runoff and recharge, the regional geothermal water is mainly supplied laterally in the far distance in the natural state, but it can be supplied from outside the area through the infinite boundary in the mining state, the hydrogeological environment is relatively closed. Therefore, the geothermal geological conditions in the project area are generalized, and a geothermal conceptual model consisting of overlying strata, thermal reservoir, thermal reservoir passage and thermal source is proposed, as shown in Figure 1.

![Figure 1. The heat storage conceptual model of Guantao-Jieshou formation in the study area](image-url)
2.3 Calculation parameters

2.3.1 Heat storage parameters.
Among the main thermal reservoir parameters involved in the calculation, the average thickness of Guantao formation is 240 ~ 425 m and the thickness of thermal reservoir is about 150 ~ 200 m according to the core drilling, comprehensive logging interpretation and geophysical interpretation. In the meantime, which of Jieshou formation is 450 ~ 700m, and the thermal reservoir is about 70m. In addition, the thermal reserve area of Neogene Guantao formation is 40.17 km², which of Jieshou formation is 40.48 km². Furthermore, the temperature of the thermal reservoir can be determined according to the temperature of the water produced from the geothermal well, geothermal geological conditions and so on, as shown in Table 1.

| Thermal reservoir      | Average thickness of heat storage d (m) | Heat storage area A (m²) | Geothermal reservoir temperature tr (℃) | Porosity Φ (%) |
|------------------------|----------------------------------------|--------------------------|----------------------------------------|----------------|
| Guantao formation I₁  | 150                                    | 11.83×10⁶                | 40                                     | 25             |
| Jieshou formation I₂  | 70                                     | 12.14×10⁶                | 53                                     | 20             |
| Guantao formation I₂  | 200                                    | 28.34×10⁶                | 43.2                                   | 25             |
| Jieshou formation I₂  | 70                                     | 28.34×10⁶                | 55                                     | 20             |

2.3.2 Physical parameters of rock and water.
The porosity of the thermal reservoir of Guantao formation and Jieshou formation is determined by using the core drilling data and comparing with the results of exploration wells in the area. In addition, according to "Geothermal resources evaluation method" (DZ40-85), the density and specific heat capacity of rocks and water of Guantao formation and Jieshou formation in this area are determined, as shown in Table 2, and the density of geothermal water is shown in Table 3.

| Rock density ρc (kg/m³) | Specific heat capacity of rock Cc (cal/kg·°C) | Specific heat capacity of geothermal water Cw (cal/kg·°C) | Average specific heat capacity of Guantao formation (cal/m³·°C) | Average specific heat capacity of Jieshou formation (cal/m³·°C) |
|-------------------------|-----------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 2600                    | 210                                           | 1000                                                     | 657057.5                                                     | 633934                                                        |

| Geothermal water temperature t °C | 40       | 43.2     | 45       | 53       | 55       |
| Geothermal water density ρw (kg/m³) | 992.2 | 990.96 | 990.23 | 986.62 | 985.67 |

3. Results and discussion

3.1 Regional geothermal reserve
According to the "Geologic exploration standard of geothermal resources" (GB/T11615-2010), the "Heat storage method" is used to calculate the geothermal resources. The Equation is as follows:

$Q_R = C \cdot A \cdot H \cdot (t_r - t_j)$

(1)

$C = \rho_c \cdot C_c \cdot (1 - \varphi) + \rho_w \cdot C_w \cdot \varphi$  

(2)

Where, $Q_R$ is the geothermal resources, J; A is the area of a thermal storage, m²; H is the thickness of reservoir, m; $t_r$ is the temperature of thermal reservoir, °C; $t_j$ is reference temperature (local annual average temperature), °C; $C$ is the average specific heat of the rocks and water in thermal storage,
\[ \rho_c \text{ is rock density in thermal reservoir, } \text{kg/m}^3; \ C_c \text{ is specific heat of rocks in thermal reservoir, J/kg} \cdot \text{°C}; \ \rho_w \text{ is density of water in thermal reservoir, } \text{kg/m}^3; \ C_w \text{ is specific heat of water in thermal reservoir, J/kg} \cdot \text{°C}; \ \phi \text{ is average porosity in thermal reservoir, } \% . \]

Considering the thickness change of thermal reservoir, the Neogene Guantao formation thermal reservoir is divided into I_1 and II_1 calculation areas. Similarly, the Paleogene Jieshou formation is divided into I_2 and II_2 calculation areas. Then, bring the parameters into Equation (1) and (2), the total amount of geothermal resources contained in the Guantao and Jieshou formation are \( 7.9767 \times 10^{17} \text{ J} \) and \( 22.4878 \times 10^{17} \text{ J} \), respectively, which are equivalent to \( 2.722 \times 10^7 \) t and \( 7.673 \times 10^7 \) t of standard coal.

### 3.2 Calculation of production capacity of geothermal single well

The FR01 geothermal well has been constructed and operated in the project area. In the test section from 560.40 m to 1193.20 m, the thermal reservoir aquifer is calculated and evaluated as the sandstones of Neogene Guantao formation and Paleogene Jieshou formation by steady-flow pumping test with three drops. The curve of geothermal well pumping test are shown in Figure 2 and Figure 3, which is exponential according to the characteristics of pumping curve. The calculation formula suitable for exponential curve is found from the hydrogeological manual, and the analytic method is used to calculate the parameter \( q_0 \) and the water output \( Q \) when the depth \( S = 20 \) m. The results are shown in Table 4.

![Figure 2. Q-S curve of pumping test](image1)

![Figure 3. q-S curve of pumping test](image2)

| Pumping sequence | Drawdown S (m) | Pumping discharge Q (m³/h) | Unit discharge q (m³/h.m) | Pumping time (h) | Settling time (h) | Water temperature (℃) |
|------------------|----------------|----------------------------|---------------------------|------------------|-------------------|-----------------------|
| S1               | 44.65          | 110                        | 2.464                     | 40               | 24                | 38                    |
| S2               | 29.77          | 89.5                       | 3.006                     | 28               | 16                | 38                    |
| S3               | 14.88          | 63.5                       | 4.267                     | 13               | 8                 | 38                    |

The pumping curve is calculated by the following Equation (3)-(5):

\[
Q = q_0 \sqrt{S} \quad \text{(3)}
\]

\[
m = \frac{\ln Q_2 - \ln Q_1}{\ln S_2 - \ln S_1} \quad \text{(4)}
\]

\[
1g q_0 = 1g Q_1 - \frac{1g S_1}{m} \quad \text{(5)}
\]

According to the above equation and the request of the relevant code: The maximum water level drop should not be more than 20 m [16], the annual recoverable amount of geothermal water is \( 6.404 \times 10^7 \text{ m}^3 \) when the depth of the well is 20 m.
3.3 Recoverable quantity and total heat of regional geothermal water
The exploitation and utilization of geothermal resources is mainly to extract geothermal water from heat reservoir. Therefore, the available geothermal resources can be calculated by the recoverable geothermal water. This project uses the average well distribution method to calculate the recoverable resources of geothermal water in the heat reservoir of the Neogene Guantao formation and Paleogene Jieshou formation in the area, as follows:

\[ Q_a = N \cdot Q_i \cdot t \]  \hspace{1cm} (6)

\[ N = A / F \]  \hspace{1cm} (7)

Where, \( Q_a \) is recoverable resources of geothermal water, \( m^3/d \); \( Q_i \) is recoverable resources of geothermal single well, \( m^3/d \); \( N \) is number of wells available in working area; \( t \) is mining time, \( d \); \( F \) is the area required for thermal equilibrium between recoverable thermal storage and total heat emission in 100 years of geothermal well exploitation, \( m^2 \); \( A \) is working area, \( m^2 \).

In the calculation parameters, the recoverable resource of geothermal single well \( Q_i \) is calculated according to the geothermal well, the \( Q_i \) of Section I is 1754.40 \( m^3/d \), that of Section II is 3275.04 \( m^3/d \), and the partition area is based on Table 1. In addition, due to the capacity of equipment and the standard requirements, determine the mining period \( t \) is 36500 \( d \). The above parameters are substituted into Equation (6) to (7), and combined with Equation (1) to (2). The results are shown in Table 5.

| Partition          | Area of partition (×10^6 m²) | Balanced area of geothermal single well (×10^6 m²) | Number of available wells | Recoverable resources of geothermal water (×10^4m³/a) | 100 years' worth of geothermal resources (×10^16J) | Converted standard coal (×10^6t) | Equivalent electric energy (MW) |
|--------------------|------------------------------|-----------------------------------------------|---------------------------|-----------------------------------------------------|----------------------------------|---------------------------------|--------------------------------|
| Geothermal Section I | 12.14                        | 3.32                                        | 3                         | 192.1                                               | 1.8419                           | 0.6285                          | 5.84                          |
| Geothermal Section II | 28.34                       | 4.13                                        | 6                         | 717.23                                              | 7.8376                           | 2.674                           | 24.85                         |
| Total              | 40.48                        | --                                          | 9                         | 909.34                                              | 9.6795                           | 3.3025                          | 30.69                         |

According to the calculation of geothermal resources, the available geothermal resources of Guantao formation and Jieshou formation in the project area are 3.4453×10^17 J, the actual recoverable geothermal water resources are 909.3406×10^4 m³/a, and the amount of water extracted from the reservoir in 100 years is 9.0934×10^9 m³, of which recoverable geothermal water resources meets the requirement of water-heat balance.

4. Conclusions
Through the evaluation of regional geothermal resources, it is shown that the geothermal resources in Yingzhou District, Fuyang are relatively rich. The total geothermal resources contained in the Neogene Guantao formation and the Paleogene Jieshou formation are 7.9767×10^17 J and 22.4878×10^17 J respectively, which are converted standard coal of 2.7220×10^7 t and 7.673×10^7 t. In the meantime, the total recoverable geothermal water resources of which are 9.093 million m³/a, the recoverable geothermal resource is 9.6795×10^6 J, which is equivalent to 3.3025×10^6t standard coal and 30.69 MW electric energy. Furthermore, the recoverable resources of geothermal water in Guantao and Jieshou formation meet the conditions of water-heat balance and water level limitation.

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