Review of geothermal power generation: a case study of ORC geothermal power generation

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Abstract. Geothermal energy is a kind of clean and renewable energy with huge resources. Geothermal power generation is a form of efficient utilization of geothermal energy. There is a big gap between the installed capacity of geothermal power generation and the new installed capacity of 500MW in the 13th five year plan. The unclear price mechanism of geothermal power generation is an important reason hindering the development of geothermal power generation. The efficiency of geothermal power generation is relatively low, and the theoretical research and technology of geothermal power generation need to be innovated. In this paper, the empirical correlation of evaporation temperature is obtained based on the cycle splitting method, and the calculation software of electric heating performance of geothermal power generation is developed. The comparison with the actual index of power station shows that the error is less than 10%. Compared with the traditional method, the calculation method based on cycle splitting method is more rapid and convenient, and the accuracy rate is more than 95%.

1. Introduction
The United Nations report on new energy shows that the total amount of global geothermal energy resources is equivalent to 450000 times of the total global energy consumption. The annual available geothermal energy in China is about 3.8 × 1010 TJ[1].

At present, the utilization modes of geothermal energy resources mainly include: 1) shallow geothermal energy extracted and utilized by heat pump technology; 2) naturally exposed hot springs and geothermal fluids directly exploited and utilized by manual drilling; 3) geothermal resources in dry hot rock (EGS). Geothermal energy resources can be divided into shallow geothermal, hydrothermal geothermal and dry hot rock geothermal. According to the temperature, geothermal resources can be divided into high temperature, medium temperature and low temperature. For high temperature, medium temperature and low temperature geothermal resources, the temperature is ≥ 150°C, greater than 100°C, less than 150°C and <100°C[2][3]. Promoting geothermal power generation technology is the strategic goal of geothermal resources utilization. At present, the total installed capacity of geothermal power generation in China is about 28mw, ranking 18th in the world. The 13th five year plan is expected to increase to 530mw by 2020[4]. There is still a great distance. In this paper, the status quo of geothermal power stations in the world is summarized, and a case study of a geothermal power station is carried out.
2. Current situation of geothermal power generation at home and abroad

2.1. Current situation of geothermal power generation in China

China's geothermal resources are equivalent to that of the United States, but the installed capacity of geothermal power generation is less than 1% of that of the United States[5]. The geothermal power stations in China are shown in Fig. 1 (gray represents shutdown, green represents operation). In fact, since the 1970s, seven different geothermal power stations have been built in China[7]. However, due to poor geothermal fluid quality, unclear physical properties of circulating working fluids, poor system optimization design, shortage of funds and policy support, some geothermal power stations have been shut down. Among them, the completion of dengwu hydropower station in Fengshun, Guangdong Province marks that China has become the eighth country in the world to realize geothermal power generation, while Yangbajing Geothermal Power Station in Tibet is the largest geothermal power station in China, with an installed capacity of 24 MW[7]. The specific situation of domestic geothermal power station is shown in the table.

2.2. Current situation of geothermal power generation abroad

Abroad geothermal power stations are mainly divided into single-stage flash and organic Rankine cycle(ORC) power generation. The statistics of specific power stations are shown in the Figure. 2. The power generation efficiency of the existing geothermal power stations is mostly between 3% and 15%, that is to say, the thermal cycle is not perfect; on the other hand, due to the lack of unified design guidelines and optimization methods, the synergy among heat source, cycle and working medium of geothermal power generation system is insufficient, resulting in uneven power generation efficiency of geothermal power generation system.

Flash and dry steam geothermal power generation system has simple structure and convenient operation, but its drainage temperature is high and its loss is large. Organic Rankine cycle has advantages in the utilization of medium and low temperature geothermal energy, but there are many kinds of working fluids and the optimal design of the system is not mature. Therefore, in order to improve the thermal efficiency of geothermal water, scholars at home and abroad have done a lot of research on geothermal power generation from the aspects of cycle series, heat source characteristics and working fluid types. However, the following problems are still worthy of further study:

1) The thermodynamic evaluation system of geothermal power generation system needs to be improved, which should cover the temperature range of geothermal fluid under economic and technological conditions as far as possible, and match the characteristics of heat source and the form of thermal cycle. 2) In the analysis and optimization of geothermal power generation system, firstly, the thermal characteristics of geothermal heat storage fluid should be mastered, and the temperature
and dryness of geothermal fluid should be considered to design, compare and optimize the geothermal power generation system; 3) In order to obtain the optimal power generation system and its optimal working conditions under the thermal characteristics of a geothermal fluid, the analysis and evaluation of different geothermal power generation systems should be established under the optimal working conditions of each system.

Figure 2. Efficiency of geothermal power station

3. Prospects of geothermal power generation in China

As mentioned above, ORC has a broad application prospect in China's geothermal resources. China's geothermal power generation system needs to be further improved in terms of cycle decoupling, working medium design optimization, system thermal economy optimization and LCA evaluation. As shown in Figure 12, the following studies still need to be paid attention to:

1) The smaller the expander capacity, the greater the technical difficulties. Therefore, the expander is one of the main bottlenecks of ORC geothermal power generation. At present, the technology of ORC expander in China is relatively backward, which has the problems of low efficiency, easy leakage of working medium and short service life. The first problem to be solved in ORC geothermal power generation is to manufacture high-efficiency and low-cost expander to improve system economy.

2) The unclear price mechanism of geothermal power generation is another important reason to hinder geothermal power generation. The development of geothermal power generation is closely related to the government policy mechanism. The lack of a clear pricing mechanism and the absence of government subsidies have led some companies to be reluctant to enter the geothermal power industry.

3) The promotion of geothermal power generation system not only considers the above ground system, but also considers the underground heat storage. In fact, the characteristics of underground heat storage are the key factors to determine the feasibility of geothermal power generation. For example, the feasibility of geothermal power generation is greatly affected by whether the production well can continuously take heat and whether the recharge is blocked. Therefore, it is necessary to strengthen the exploration of geothermal resources, solve the problem of recharge, and study the economically feasible anti-corrosion and scale prevention technology.

4) The theory and technology of geothermal power generation need innovation. The EU has a mature technical system in geothermal power generation such as dry hot rock. China should optimize the geothermal power generation technology and innovate the theory according to the actual situation of geothermal resources, so as to reduce the cost and gain competitive advantages.

4. ORC geothermal power generation case analysis

For geothermal resources in China, ORC geothermal power station has broad application prospects. At present, the largest Yangyi geothermal power station in China adopts ORC technology. There are
many achievements in geothermal ORC research, but there is still a lack of fast calculation software. The most important factor is how to get the maximum thermal power output and maximum thermal mass output of the system. There are many methods to determine the optimal evaporation temperature. Most of the current researches are based on the calculation of the overall performance of the system, and there is no relatively independent calculation criterion formula.

In this paper, the evaporation temperature can be linked with the physical properties of working medium and heat source temperature based on the cycle splitting method[8], and the correlation coefficient is obtained by simulation calculation, and the accuracy is high. ORC system diagram and T-S diagram are shown in Figure. 3. According to the energy conservation equation and the empirical correlation of the best evaporation temperature, the program is compiled, the energy conservation equation is shown in Table 1. The calculation parameters are shown in Table 2.

The empirical correlation of the best evaporation temperature is:

\[ T_{\text{eva, opt}} = C \cdot T_{\text{cri}}^m \cdot \omega_{\text{cry}}^n \cdot T_{\text{hs}}^o \]  \hspace{1cm} (1)\]

Where \( C = 0.505526 \), \( m = 0.0455956 \), \( n = 0.056832 \), \( o = 1.020186 \).

| Equipment          | Energy Conservation Equation |
|--------------------|-------------------------------|
| Heat source pipe   | \( m_{h, in} h_{hs, in} = m_{h, out} h_{hs, out} - Q_{\text{loss}} \) |
| evaporator         | \( m_e (h_{e, in} - h_e) = m_e (h_e - h_e) \) |
| Preheater          | \( m_h (h_s - h_{hs, out}) = m_e (h_s - h_s) \) |
| condenser          | \( m_h (h_e - h_h) = m_e (h_{e, out} - h_{e, in}) \) |
| expander           | \( m_h = m_h + W_{\text{exp}} \) |
| Fluid pump         | \( m_h (h_h - h_h) = W_h \) |

\[ Q_0 = m_h (h_h - h_{f, out}) \]  \hspace{1cm} (2)\]
\[ W_{\text{net}} = W_{\text{exp}} - W_h \]  \hspace{1cm} (3)\]
\[ \eta = \frac{W_{\text{net}}}{Q_0} \]  \hspace{1cm} (4)\]

Where \( Q_0 \), \( W_{\text{net}} \), \( \eta \) are Heat absorption, net work, thermal efficiency.

![Figure 3](image-url)
Table 2  Case parameters

| parameter          | data  | Unit |
|-------------------|-------|------|
| heat source temp  | 168   | ℃    |
| heat source flow  | 620   | t/h  |
| Heat source quality | 10   | %    |
| NCG               | 0.16  | %    |
| injection temp    | 65    | ℃    |
| injection pressure | 2    | MPa  |

According to the energy conservation equation and the optimal evaporation temperature correlation, the ORC geothermal power generation system thermal performance calculation software is compiled. The calculation results are compared with the operation parameters of an ORC geothermal power station, and the results are shown in the table 3. The thermodynamic indexes are all less than 10%.

Table 3 Comparison of software calculation result and actual situation

| Index                  | Calculation | Actual | Unit | Error   |
|------------------------|-------------|--------|------|---------|
| electric energy production capacity | 17655.7     | 18870 | kW   | -6.4%   |
| thermal efficiency     | 14.84       | 16     | %    | -7.25%  |
| Inlet temperature of expander | 156.4       | 142.8  | ℃    | 9.52%   |
| Inlet pressure of expander | 1.76        | 1.66   | MPa  | 6.02%   |

5. Result

Geothermal energy is a kind of clean and renewable energy with huge resources. Geothermal power generation is a form of efficient utilization of geothermal energy. Through summarizing the current situation of geothermal power generation and actual case analysis, the following conclusions are obtained:

1. The efficiency of geothermal power generation is low, and the efficiency of geothermal power generation is mostly between 3% and 15%, which is mainly due to the poor perfection of thermal cycle and the lack of coordination among heat source, circulation and working medium of geothermal power generation system.

2. There are many problems in geothermal power generation, such as blocking, scaling and corrosion in production wells and recharge wells, which will cause the system to be forced to shut down.

3. In the total investment of geothermal power generation, power station investment, drilling investment and other miscellaneous items account for about 1/3 of the total investment. The operating cost of geothermal power station is very low, and the income is mainly used to offset equipment depreciation and recover the initial investment. Unclear price mechanism is the main reason hindering the development of geothermal power stations.

4. The biggest risk of geothermal power generation lies in heat storage engineering, that is, how to obtain a higher flow of geothermal fluid circulation under the minimum drilling investment.

5. The thermal calculation software of ORC geothermal power generation system is developed, and compared with the actual indexes of the power station, the error is less than 10%.

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