Thermodynamic Performance Analysis of Geothermal and Solar Energy Medium - low Temperature Combined Power Generation System

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Abstract: Taking the capacity expanded geothermal and trough type solar power combined generation system as the research object, the temperature at outlet of the solar energy collection was estimated to obtain the optimum outlet temperature. Evaluation models for such indexes as generation efficiency, the increasing ration of power generation capacity and solar energy utilization fraction were set up to analyze the thermal performance of this system. By applying the Aspen Plus software, the geothermal-solar energy combine power generation system model for the geothermal power station in DPR of Korea was established. Moreover sensitivity analysis and optimization tool were used to calculate major parameters of this system, to obtain the best capacity expansion temperature, which is helpful to the system' s capacity expansion. The results show that, after the optimization, the generation power of the system was 4 044.5KW, the generation efficiency was 13.1% the hot water consumption was 94Kg/(KW·h), the steam consumption rate was 9.2Kg/(KW·h), the solar energy utilization percentage was 58.1% and the power generation increment ratio was 30.0%. Each performance index of the system enhanced significantly.

Key words: geothermal; solar energy; hybrid power generation; thermal performance; evaluation model; system model.

As a kind of renewable energy, geothermal energy is widely used in heat utilization and power generation [1].

According to the different geothermal resources, can be divided into direct steam, expansion, inter -mediate medium flow and full circulation four kinds of basic power generation [2]. Compared with other methods, this method has the advantages of simple system, lower requirements on equipment, less impact on environment after strengthening recharge management, etc., but the power generation efficiency is low. In addition, the long-term large-scale development and utilization of geothermal resources, such as the continued operation of geothermal power station for 30 years, may cause problems of thermal storage pressure decay, steam flow reduction and hot water temperature decrease, which will further reduce the system efficiency. To this end, the use of organic Rankin cycle, or geothermal energy and solar energy, fuel super heater and other energy combine to improve the steam temperature, increase power generation capacity and reduce the system's dependence on geothermal energy [3-4]. Based on the expanded geothermal power generation, this paper increases the light and heat energy to heat the steam and effectively combines the geothermal energy and the solar energy to improve the power generation efficiency and extend the useful life of the geothermal resources [3-4].

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1 hybrid power system principle

The geothermal-solar combined power system (Figure 1) uses a trough heat collector to concentrate low-energy density solar energy and convert it into heat of high enough temperature to heat a heat-carrying substance (such as heat-conducting oil) to a certain temperature. Geothermal water into the expansion tank, while reducing the pressure in the expansion, the flash to get part of the saturated steam; high-temperature heat transfer oil through the heat exchanger saturated steam, overheating; superheated steam turbine generator power generation; steam turbine through the lack of steam After the condenser is cooled, it is mixed with the remaining hot water in the expansion tank and recharged to the geothermal field after treatment. Compared with the traditional expansion geothermal power generation, the system increases the solar collector subsystem, heat transfer oil circulation subsystem and heat exchanger, etc., to improve the turbine inlet steam temperature to make it Power capabilities increase, thereby increasing system efficiency.

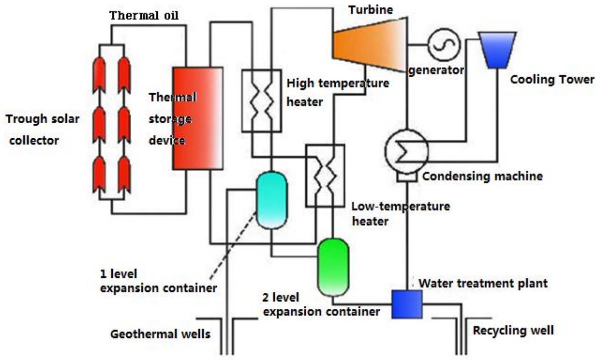

Fig.1 The geothermal-solar power generation system

Compared with the geothermal resources, solar energy has poor stability and is greatly affected by the environment and climate. The operation of the combined system requires sufficient solar energy. Taking the Lhasa region of Tibet as an example, this region is a type of solar energy resources in our country. The annual sunshine duration is up to 3 000 h, the annual total radiation is 6 6 680-8 400 MJ / m^2, the average sunshine intensity is more than 8 h / d, For the operation of the thermal subsystem provides a good resource conditions. The combination of solar thermal subsystem and geothermal power station can realize the optimal utilization of geothermal-solar energy, which is favorable for the matching of power generation and electricity load. In the night with low electricity load, it can be switched to the traditional expansion type geothermal power generation operation mode. In the daytime with high electricity load, geothermal-solar power generation can effectively improve system efficiency and power generation. In the early morning hours, the thermal subsystem can be operated alone. After the temperature of the thermal storage device reaches the system requirement, the entire power generation system can be operated jointly. The heat storage device can eliminate the drawbacks of instability of solar energy to a certain extent and make the temperature of the steam turbine enter the steam constant, which ensures the stability and reliability of the power output.

2 Estimation of thermal performance

The thermal performance of the geothermal-solar hybrid system depends mainly on the degree of perfection of the solar thermal subsystem (ie, the efficiency with which the collector collects solar energy) [5-6] and how well the thermal collector matches the steam power plant Thermal cycling efficiency). The heat collecting efficiency decreases with the increase of the temperature of the heat carrier at the outlet of the collector, but the thermal cycle efficiency increases accordingly. which is:

$$\eta = \eta_c \cdot \eta_t \quad (1)$$

In the formula, η is the total system efficiency, η_c is the heat collection efficiency, and η_t is the heat cycle efficiency.

From the perspective of the system as a whole, there is an optimal operating condition of the collector (ie, the best outlet temperature of the collector), resulting in the highest overall system efficiency. This paper uses the simplified thermal analysis method [7-8] to estimate the thermal performance of the combined system. Collector efficiency is:

$$\eta_C = (\tau\alpha)\rho - \frac{\varepsilon\sigma}{I_c}(T_C^4 - T_a^4) \qquad (2)$$

In simplifying the calculation, without considering the pipeline loss in the system, heat loss, etc., the total efficiency of the joint system is:

$$\eta = \left(\frac{T_C - T_a}{T_C}\right)\left[(\tau\alpha)\rho - \frac{\varepsilon\sigma}{I_C}(T_C^4 - T_a^4)\right] \qquad (3)$$

$(\tau\alpha)$ is the absorption product, $(\tau\alpha) = 0.85$; ρ is the reflectivity of the reflector, $\rho = 0.9$; ε is the collector surface emissivity of the collector, ε = 0.9; σ is the black body radiation constant, $\sigma = 5.67 \times 10^{-8} \mathrm{w}/(m^2 \cdot K^4)$; I is the solar radiation intensity, $\mathrm{I} = 700\mathrm{W}/m^2$; c is the collector concentration ratio, c = 100 ; T_a is the annual average ambient temperature, $T_a = \mathbf{2.5}$℃; T_c collector outlet temperature, ℃.

Deriving the equation (3) and making it equal to 0, we get: $\frac{d\eta}{dT_C} = T_C^5 \frac{4\varepsilon\sigma}{I_C} - T_C^4 \frac{3T_a\varepsilon\sigma}{I_C} - T_a\rho(\tau\alpha) = 0$ (4)

By equation (4) the best $T_C = 367℃$.
After calculating the total system efficiency with the outlet temperature of the collector as shown in Figure 2.

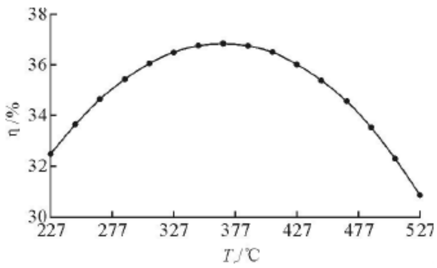

Fig.2 Variation of the system overall efficiency against the temperature at outlet of the solar thermal collector

3 Thermal economy evaluation index

The geothermal-solar-thermal power generation system is analyzed with the evaluation index of power generation efficiency, geothermal water consumption per kWh, total power generation, power generation increment ratio XE and solar energy utilization fraction XQ [9]. Power generation efficiency is:

$$\eta_S = \frac{E}{Q_W + Q_S} = \eta_C \eta_b \eta_p \eta_t \eta_{ri} \eta_m \eta_g \qquad (5)$$

Where: η_S is the power generation efficiency,%; E is the actual output power of the system, KW; Q_W、Q_S are the heat input into the system of geothermal and solar energy, KW;
η_C, η_b, η_p, η_t, η_{ri}, η_m, And η_g are the heat collection efficiency, thermal insulation efficiency during heat storage and heat exchange, pipeline efficiency, turbine internal efficiency, mechanical efficiency and generator efficiency respectively. %.
X_E is the ratio of geothermal-solar-thermal power generation to the total power generation provided by a single geothermal power generation, and X_Q is the ratio of solar energy input to the total input energy. These two indicators can visually show the impact of solar fluctuations on the system and help to evaluate the thermal economy of the actual operating conditions of the combined power generation system.

$$X_E = \frac{E - E_G}{E} \quad (6), \qquad X_Q = \frac{Q_S}{Q_W + Q_S} \quad (7)$$

Where, E_G under the same conditions, the separate operation of geothermal power generation system.

4. Thermal performance simulation calculation

4.1 Model establishment

On the basis of the original level 2 expansion, increase the solar energy subsystem. Through heat transfer oil and flash steam saturated steam 2 heat transfer, steam turbine to improve import parameters, so as to achieve the purpose of increasing power generation. After simplifying the geothermal-solar hybrid system, the model built with Aspen Plus software [10] is shown in Figure 3.

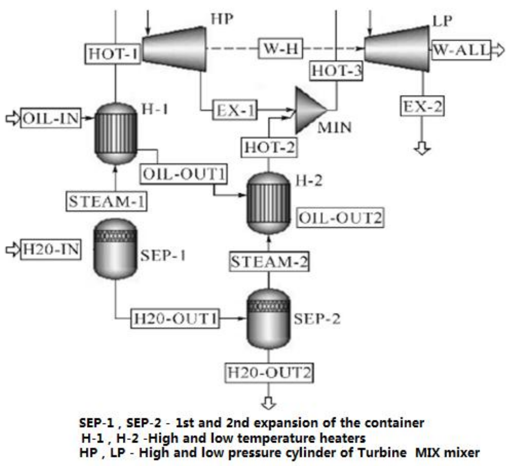

Fig3. Simulation model of the geothermal-solar power generation system by using Aspen Plus software

According to the actual situation of geothermal power plant [11], geothermal water temperature is set as 145 ℃, pressure is 550KPa and flow rate is 380t / h; the flashing temperatures of the two stages are 114 ℃ and 81 ℃ respectively; 8.826 KPa at 3 000 rpm with a relative internal efficiency of 0.78 and a mechanical efficiency of 0.98. Local thermal - solar thermal operation, from the above estimates were 1-level heater HTF inlet temperature of 367 ℃, so choose Dow Chemical HTF Dowtherm A (maximum working temperature up to 400 ℃), and set its flow For 22t / h. When the local thermal system operates alone, the HTF flow rate is zero.

As the main working fluid in the model is water and steam, STEAM-TA using Aspen Plus software is chosen as the global property method. For the heat transfer oil side, PENG-ROB physical property method based on PR state equation is selected [10].

4.2 Simulation results and analysis

(1) Table 1 shows the comparison between the simulation results of the main parameters of the geothermal-solar thermal power generation system and the geothermal power generation system. As can be seen from Table 1, the geothermal-solar power generation system significantly increases the power generation ratio of the geothermal power generation system, significantly increases the power generation efficiency of the system, significantly reduces the amount of hot water consumption and the steam consumption rate of the power consumption, and as the system introduces solar energy, Under the same conditions, the temperature of the spent steam is increased by 22.1 ℃. In order to improve the thermal economy of the system, the two-stage expansion temperature should be re-selected [12]. The sensitivity analysis and optimization tools of Aspen Plus software are used to simulate the condition , The best two-stage expansion temperature is 116,86 ℃, the system power is 4 044.5KW, the power generation efficiency is 13.1%, the degree of electricity consumption of geothermal water is 94Kg / (KW • h), the steam consumption rate is 9.2 Kg / (KW • h), the utilization ratio of solar energy is 58.1%, and the incremental ratio of power generation is 30.0%. All the performance indexes of the system have been significantly improved, and the proportion of solar energy in the system has increased, making the geothermal-solar power generation system The advantage is more prominent.

Table1. Simulation results of the major parameters

Project	Geothermal - Solar hybrid System	Geothermal power generation system
High-pressure cylinder into the steam temperature / ℃	317.0	114.0
High-pressure cylinder into the steam pressure / KPa	163.7	163.7
High-pressure cylinder steam flow / $(t \cdot h^{-1})$	22.7	22.7
Low-pressure cylinder into the steam temperature / ℃	189.3	81.0
Low-pressure cylinder into the steam pressure / KPa	49.3	49.3
Low pressure cylinder steam flow / $(t \cdot h^{-1})$	44.2	44.2
Lack of steam temperature / ℃	65.5	43.4
High temperature heater outlet heat transfer oil temperature / ℃	176.3	
Low temperature heater outlet heat transfer oil temperature / ℃	96.0	
Power generation incremental ratio /%	28.9	
Solar energy utilization score /%	10.3	
Power generation /KW	3 981.73	2 829.59
System power generation efficiency /%	10.9	8.6
Electricity consumption of hot water / $(Kg \cdot (KW \cdot h)^{-1})$	95.4	134.3
Steam consumption rate / $(Kg \cdot (KW \cdot h)^{-1})$	11.1	15.6

(2) Taking into account the decay of geothermal resources, solar energy fluctuations and other factors on the system, geothermal water and heat transfer oil heater inlet parameters will change, leading to the system changes working conditions. Sensitivity analysis function of Aspen Plus software is used to simulate the operation of the system under variable working conditions. Taking the inlet temperature, geothermal water flow and inlet temperature of HTF HTF as a relatively large environmental impact factor as an example, the influence of the changing working conditions on the system is shown in Fig. 4 and Fig. 5 respectively. From Fig. 4 and Fig. 5, it can be seen that the power generated increases with the inlet temperature of the HTF oil at a high temperature. The two are approximately linear and the gradient of power variation is about 5 KW / C. Under the same conditions of geothermal water flow, The higher the power is, the linear gradient of power is about 72.7KW / ℃.

At the same temperature, the greater the geothermal water flow, the greater the power generation. Therefore, the change of geothermal water inlet parameters has a great influence on the power generation of the system. This is because the geothermal water temperature, flow changes will directly affect the volume of saturated steam expansion, and thus affect the turbine output power.

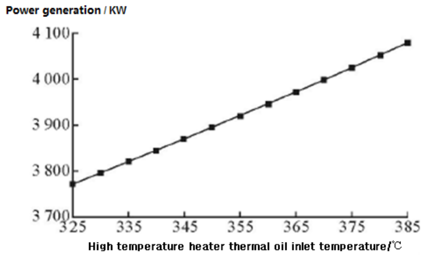

Fig.4 The influence of oil inlet temperature on power generation

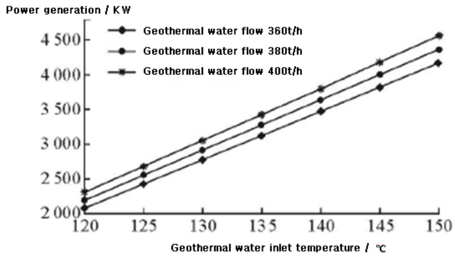

Fig.5 The influence of geothermal water temperature and flow rate on power generation

5 Conclusion

1) Compared with the traditional expansion-type geothermal power generation technology, the geothermal-solar combined power generation system is more efficient, generates more power, consumes fewer amounts of hot water and the steam consumption rate, and significantly improves the thermal economy.
2) The higher the geothermal water temperature, the greater the flow rate, the higher the inlet temperature of the HTF in the heater, the greater the system power will be generated. And in the case of constant expansion temperature, the parameters of geothermal water have a greater impact on the thermal economy of the system.
3) The expansion temperature directly affects the steam turbine intake, thus affecting the power generation. In the geothermal - solar system operating conditions change, it should be reasonable to adjust the expansion temperature.
4) Ratio of power generation increment and solar energy utilization can intuitively show the impact of solar energy fluctuations on the system, which is helpful to evaluate the thermal economy of the actual operating conditions of the combined power generation system.

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