Operation analysis and optimization of geothermal heating system

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Abstract: Under the background of "double carbon", the proportion of medium and deep geothermal heating as a clean energy will be further increased. Therefore, how to improve the operating efficiency of the medium and deep geothermal heating system is of great significance for energy conservation and emission reduction. In this paper, taking a geothermal station as the research object, referring to the production and operation data of five years, two improvement measures are proposed, such as adopting the operation mode of "large temperature difference, small flow", reasonably arranging the start and stop time of geothermal wells (submersible pumps), heat pumps and other equipment in the station, which can significantly reduce the system energy consumption level. Combined with the operation characteristics of the geothermal system, the electricity consumption and heat transmission ratio of the heating system of different users and the secondary network system with small temperature difference such as the medium and deep geothermal heating system are compared, which is not suitable for long-distance heating services.

Key words: geothermal, cascade utilization, energy efficiency analysis, optimization

1. Introduction

Geothermal resource refers to the geothermal energy, geothermal fluid and its useful components in the earth that can be economically used by human beings. It is a green, low-carbon and recyclable renewable energy [1]. China's geothermal resources are mainly medium and low temperature hydrothermal geothermal fields, which are characterized by wide distribution, huge reserves, low difficulty in development and utilization, and have become a new type of renewable energy [2]. In order to make full use of geothermal resources, the cascade utilization of geothermal energy is realized to improve the energy conversion efficiency according to the energy use idea of "matching taste and cascade utilization".

The taste of geothermal resources in China is close to the circulating temperature of central heating system, and geothermal heating has been developed on a large scale in China in combination with local social and economic conditions. However, geothermal heating is a livelihood project with long cycle and slow income. To improve the investment efficiency of enterprises, it is necessary to continuously optimize the equipment selection and configuration, take energy-saving control and other measures to reduce costs [3]. It can be seen from the production and operation data collection and analysis of Nova in recent years that submersible pumps, heat pump units and other energy consuming heat pumps are the key to energy efficiency optimization of geothermal heating systems.

2. Geothermal heating system

2.1 Geothermal heating system

According to the change of heating load, two types of geothermal heating systems are mainly adopted, namely, "geothermal indirect heating" and "geothermal indirect heating+heat pump peak shaving".

It is mainly composed of geothermal system, heating circulating pump, heat pump unit, water make-up system, electrical system, automatic control system and other subsystems. The geothermal system includes geothermal well, submersible pump, heat exchanger, reinjection booster pump and primary pipe network; The make-up water system includes demineralized water device, make-up water tank, constant pressure make-up water pump, etc.

By exploiting medium and deep geothermal water, the method of energy cascade utilization is adopted. The first stage is indirect heat exchange between geothermal water and heating water, and the second stage is indirect heat exchange between geothermal water and intermediate water to provide low temperature heat source for the heat pump system. In the whole process, geothermal water is only used for heat carrier transmission, and does not consume or discharge geothermal water. The heating circulating water is heated by the direct supply plate heat exchanger and heat pump, and the building is heated by the closed circulation system. The system process flow diagram is shown in Figure 1.

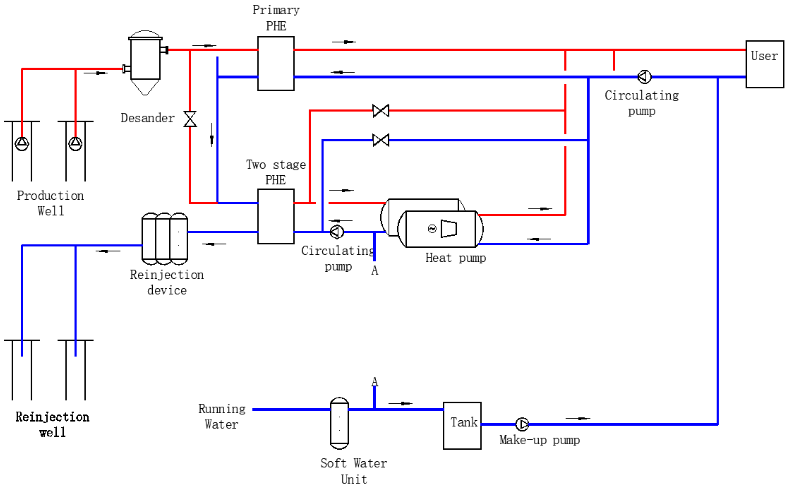

Fig. 1 Flow Chart of Geothermal Heating System

2.2 Index of energy consumption evaluation

The power and heat transmission ratio EHR-h of central heating system is defined in GB50189-2015 Design Standard for Energy Efficiency of Public Buildings [4],. The definitions are as follows:

$$EHR-h = 0.003096\sum(G \times H/\eta_b)/Q \leq A(B+\alpha\sum L)/\Delta T \qquad (1)$$

G—Design flow of each operating water pump (m ³/ h)

H—Design head corresponding to each operating water pump (m)

η_b—Design working point efficiency corresponding to each operating water pump

Q—Design heat load (kW)

ΔT—Design water supply and return temperature (℃)

A—Calculation coefficient related to pump flow

B—calculation coefficient related to the water resistance of the machine room and users, B is 17 for the primary pump system and 21 for the secondary pump system

ΣL—total length of water supply and return pipeline from heating station to heating end (radiator or radiant heating water collector) (m)

α— And ΣL related calculation coefficient

This indicator comprehensively reflects the influence of heat load, temperature difference between supply and return water, pipe network length and form on the energy efficiency of the heating cycle system under design conditions. This paper uses EHR-h as the evaluation index of geothermal heating cycle system to analyze the energy consumption of heating pipe network.

3 Typical site analysis

Qingfeng area, Puyang City, Henan Province, is located in the east of Neihuang bulge. The geothermal resources are abundant and easy to exploit. The geothermal fluid temperature is 52~55 ℃, and the water temperature is about 110m3/h. Since 2014, medium and deep geothermal resources have been used for building heating on a large scale. By the end of 2020, a total of 2.811 million square meters of geothermal heating capacity has been built, 5 geothermal stations have been built, and 18 geothermal wells have been drilled.

This paper selects a geothermal station as the first geothermal project in Qingfeng District. The first well was drilled in 2013, with a designed heating capacity of 450000 square meters, a thermal load of 15.2MW, and five geothermal wells drilled. Through years of production and operation, the operation mode has been continuously improved and refined management has reduced the level of energy consumption in the station to a certain extent, but the operation mode of submersible pumps, circulating pumps and heat pump units in the station is still rough.

3.1 Impact of heating circulating water supply and return temperature on energy consumption in the station

At the design stage, the operation mode of the national geothermal heating project is still being explored. The heating terminal is designed according to the radiator, and then the heating cycle water supply and return is designed to be 43/50 ℃. The space for direct utilization of geothermal energy is small. The ends of geothermal heating projects are mostly new buildings in recent years, and the indoor ends are mostly floor heating. Therefore, according to JGJ142-2012, the heating cycle operating temperature will be reduced to 35/45 ℃ during the construction of Phase II.

Table 1 Impact of return water temperature at secondary side on total energy consumption

Return water temperature(℃)	Indirect heating load(kW_t)	Heat pump load(kW_t)	Total heat load(kW_t)	Secondary side power consumption(kW_e)	Heat pump power consumption(kW_e)	Total energy consumption(kW_e)
43	895.51	3437.5	4333.01	103.7885	754.4591	858.2476
35	1918.95	2337.5	4256.45	110.6828	502.2348	612.9175

As shown in Table 1, the energy of geothermal heating system is mainly composed of geothermal energy indirect heat exchange load and heat pump cascade utilization load, and the energy consumption mainly comes from the secondary side system and heat pump system. Among them, according to different tastes of geothermal resources in China, heat pump heating load accounts for 40-60%, and heat pump electrical load accounts for 65-75%. Therefore, reducing the load rate of heat pump unit is an important means to improve the economy of geothermal heating. It can be seen from the following formula that the COP of the heat pump unit is mainly affected by the input temperature and output temperature of the heat pump. By reducing the output temperature of the heat pump, the COP of the unit can be significantly improved and the system power consumption can be reduced. As the temperature of the secondary side decreases, the heat taken by the primary heat exchanger increases. The change of the temperature of the heating circulating water under quality regulation with the temperature is shown in Figure 2. The primary plate exchanger provides more energy at low load rates, further reducing the heat pump load and helping to reduce the system energy consumption.

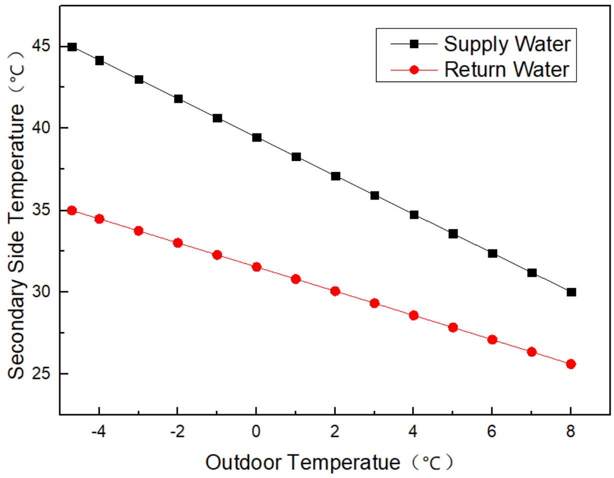

Fig. 2 Influence of Outdoor Temperature on Secondary Side Temperature

3.2 Impact of secondary side system on station energy consumption

As shown in Table 2, a geothermal station uses a branch pipe network to connect 11 heating users, with a total energy load of 13795kW. Each load is distributed along the 3km heating pipeline, and the secondary station layout is adopted according to the user's static water head. There are 4 booster stations along the line, and the design heating cycle volume is $1867m^3/h$.

Table 2 Access load of a geothermal station

User	heat load（kW）
YHZT	2508.8
YYFJ	1461.6
YD	840
YHHD	2136.4
SWTY	5544
Public buildings 1-6	1304
Total	13794.8

According to the analysis of production data, the heating circulation system maintains a temperature difference of 6~8 ℃ between the supply and return water, does not adopt the operation strategy of "large flow, small temperature difference" adjustment, and the operation temperature fluctuates slightly with the temperature of the day. The average EHR-h is 0.034, which is greater than the specification requirement of 0.013. There is a large space for energy consumption optimization in the station. Because the main pipeline of the secondary network is long and the pipeline resistance is large, in order to meet the heating demand of the most unfavorable point, the lift of the circulating pump is selected to be large. Specifically, the overall EHR-h value of each heating load is on the high side, and the gap with the reference value is increased according to the law from far to near. According to Formula (1), it can be seen that the long-distance heating service is not suitable for the secondary network system with small temperature difference, such as the medium and deep geothermal heating system.

Table 3 EHR-h of Main Loads

用户	Distance from geothermal station (km)	First stage pump		booster pump		EHR-h	
		Flow (m^3/h)	Head (m)	Flow (m^3/h)	Head (m)	Actual	Reference
YHZT	0.2	269.6475	43			0.019078	0.008098
YYFJ	0.2	157.0937	43			0.019078	0.008333
YD	1.4	90.28375	43	90.28375	30	0.032389	0.015555
YHHD	1.8	229.6217	43			0.019078	0.015686
SWTY	3.2	595.8727	43	595.8727	50	0.041262	0.024428
公建 1-6	1.8	140.1548	43			0.019078	0.016142

In the operation mode of "large temperature difference, small flow", the difference between the supply and return water temperature of the heating cycle is increased from 6~8 ℃ of the actual operating temperature difference to 10 ℃ under the design condition, and the heating cycle volume is reduced by 20~40%, while the power of the water pump is in direct proportion to the cycle volume, and the secondary side cycle energy consumption can be reduced by more than 20%.

3.3 Impact of equipment operation strategy on station energy consumption

The energy of geothermal heating system is mainly composed of geothermal energy indirect heat transfer load and heat pump cascade utilization load. The indirect heat transfer load of geothermal energy is the direct heat exchange between the geothermal fluid and the heating circulating fluid through the plate heat exchanger. In the whole process, only the water pumps of the primary network and the secondary network are required to do work, and the system energy efficiency ratio is more than 10. The cascade utilization of heat pump is limited by the performance of heat pump unit, and the energy efficiency ratio is mostly less than 5. According to the analysis of the measured data, the energy efficiency ratio of the whole geothermal heating system can reach more than 8 on average, which is far higher than that of the pure heat pump energy supply system and the coal-fired gas boiler heating system.

Therefore, in the actual heating operation process, more geothermal wells are often opened at medium and low loads, and the circulating temperature of the secondary network is adjusted according to the quality regulation method shown in Figure 2, so as to increase the energy provided by the indirect heat exchange load and reduce the starting time of the heat pump unit.

Table 4 Cumulative Operation of Geothermal Wells

Year	Accumulative operation (d)
2016	120
2017	241
2018	294
2019	250
2020	309

As shown in Table 4, the project adopts the operation strategy of two geothermal wells to provide continuous load and one geothermal well to supplement additional energy in the coldest month. In the cold winter of 2020, by extending the operation time of the third geothermal well and increasing the discharge capacity of submersible pump, the heat output is effectively guaranteed and the heating operation is guaranteed. Three centrifugal heat pump units are installed in the station. Due to the operating characteristics of motors and compressors, the adjustment range of output power of a single heat pump unit is limited. Therefore, the mode of adjusting the number of equipment as required is adopted during operation. To sum up, the energy consumption of system operation can be significantly reduced by reasonably arranging the operation strategy of equipment in the station.

4. Conclusion

In this paper, a geothermal station is taken as the research object, combined with the operating characteristics of geothermal system, and according to the operating data over the years, the operation is analyzed. The following operation strategies are proposed to reduce operation energy consumption and improve the economic benefits of the project.

(1) The operation mode of "large temperature difference, small flow" is adopted to increase the temperature difference between the supply and return of heating circulating water, and the operation is carried out according to the design value of 10 °C. The heating circulating quantity is reduced by 20~40%, and the circulating energy consumption at the secondary side can be reduced by more than 20%.

(2) According to the analysis of system power consumption and heat transmission ratio, from the perspective of energy conservation, the secondary network system with small temperature difference, such as medium and deep geothermal heating system, is not suitable for long-distance heating service.

(3) By reasonably arranging the startup and shutdown time of geothermal wells (submersible pumps), heat pumps and other equipment in the station, increasing the indirect heating load and reducing the startup time of heat pumps can significantly reduce the system operation energy consumption.

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