Research on New Geothermal Cascade Utilization System Suitable for Rural Areas

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Abstract. Geothermal energy is a kind of sustainable renewable and clean resources. However, when using this energy source, there are serious problems such as excessive tail water discharge and insufficient utilization of geothermal energy. Especially in rural areas, how to use geothermal energy at low cost and efficiently is an urgent problem to be solved. The use of geothermal cascade can reduce the temperature of tail water to a certain extent, make full use of geothermal energy in each temperature section, and increase the utilization rate of geothermal energy. Based on the research status of geothermal cascade utilization at home and abroad, this paper proposes a new type of rural geothermal cascade utilization system, and attempts to analyze this system, and finds that this system can increase the utilization rate of geothermal energy at low cost.

1. Introduction
Geothermal energy is a kind of renewable clean energy from the depths of the earth. Since the first time in 1904, the Conti Prince of Italy used geothermal steam to generate electricity. The huge potential energy of geothermal energy has gradually entered people's lives and has been widely used in many countries.

With the increasing shortage of fossil energy and the increasing awareness of environmental protection, people are paying more and more attention to the rational development and utilization of geothermal resources. In Europe, as of 2012, geothermal direct utilization capacity reached 24.3GW[1]. In China, geothermal resources are mainly used directly. In recent years, the scale of geothermal utilization has been ranked first in the world and is growing at a rate of about 10% per year. As of 2014, ground-source heat pumps accounted for 58% of geothermal heat utilization. Geothermal heating accounts for 19%, and hot springs account for 18%[2]. This proportion shows the technical and energy development of geothermal energy.

Although geothermal resources can be regenerated, they must be properly exploited and maintained. Due to the wide range of geothermal fluids available at different temperatures, many countries have adopted cascade development and comprehensive utilization methods in order to improve geothermal utilization. This is also the most effective use of geothermal resources to make their thermal efficiency highest.

2. The principle of geothermal cascade utilization
The geothermal cascade uses the deep geothermal water, and the heat is exchanged from high
temperature to low temperature through heat exchange equipment with different temperature requirements, so that it can reach the suitable tail water temperature and recharge or discharge it. In the comprehensive utilization of geothermal cascades, it is usually provided to different suitable fields according to the temperature. The range of fluid temperatures required by different fields of technology is shown in Table 1.

| Applicable field                                                                 | Temperature range |
|----------------------------------------------------------------------------------|-------------------|
| Drying of organic matter, seaweed, pasture, vegetables, washing and drying of wool| Around 100°C      |
| Store fish for drying, fortified ice melting                                      | Around 90°C       |
| Building heating, crop planting greenhouse heating, milk disinfection              | Around 80°C       |
| Beet sugar extraction                                                            | Around 70°C       |
| Heating in animal housing, greenhouse space and low temperature                  | Around 60°C       |
| Mushroom cultivation, spa treatment                                               | Around 50°C       |
| Soil heating, hot spring bath                                                     | Around 40°C       |
| Swimming pool, fermentation, biological degradation, antifreeze                   | Around 30°C       |
| Hot spring fish farming, water lotus culture                                      | Around 20°C       |

3. Research status at home and abroad

In the United States, the first use of geothermal energy for heating was in Idaho in 1892, with a heating range of up to 400 households[3]. In Izmir–Balçova, Turkey, the first use of geothermal energy for heating in 1981, the first use of downhole heat exchangers, and in 1987 realized the operation of Turkey's first urban-based district heating system[4]. In Greece, scholar Constandinia Panagiotoun[5] proposed that geothermal water can be applied to other places according to its temperature after indoor heating, thus obtaining the level of geothermal cascade utilization.

In China, Dou Ming[6] et al. explored the development and utilization mode of geothermal water cascades in Anyang City, Henan Province. According to the actual situation in the local area, on the basis of calculating the thermal reserves, different needs for hot water for different application fields. With the water temperature and water quality of geothermal water, five kinds of geothermal water development and utilization modes were proposed to increase the recycling of geothermal water, reduce the discharge temperature of tail water, and improve the comprehensive utilization efficiency of geothermal water. He Manchao[7] et al. used the actual project in Tianjin as an example to discuss the sustainable development and utilization of geothermal resources, and introduced the geothermal well dynamic irrigation prediction technology and geothermal cascade utilization technology. In the actual project, geothermal cascade development and recycling development was adopted. Four levels of utilization, and separate independent systems with three different parameters for heating. Liu Fengyu[8] studied the multi-step comprehensive utilization technology model of geothermal water, including geothermal radiant heating technology, ground source heat pump technology, new plate heat exchange technology and geothermal water recharge, and applied it to the example to verify its Practicality.

4. Common forms of cascades utilization

There are several ways to use the geothermal cascade in actual engineering: directly through multiple plate heat exchangers, use at the end to improve the geothermal heat, use plate heat exchanger + water source heat pump, plate heat exchange + absorption Heat pump.

4.1. Multi-plate heat exchanger step utilization

In the initial stage of comprehensive utilization of geothermal cascades, most of the actual projects use only two or even multi-stage plate heat exchangers for simple cascade utilization of geothermal heat. For example, in a hotel with accommodation, swimming, catering, and spa that was first used in the use
of geothermal water cascades in Beijing, direct heating is used for the comprehensive utilization of geothermal water, and heating and return water is used for swimming pools and bathing water. The initial investment and operation costs are low, and this does improve the utilization of geothermal energy. However, in addition to swimming pools and bathing water, there is usually a large amount of tail water discharge, resulting in serious waste of resources and even environmental pollution.

4.2. Step utilization of end product improvement

With the increasing end product of the heating system, it is possible to select the appropriate end for the cascade utilization according to the temperature range of the geothermal water. The user demand for the heating temperature is as follows: heating at 65-60 °C using a radiator, living at 60-55 °C Preparation of hot water, 45-50 °C using fan coil heating, 40-45 °C using floor radiant heating, 28-30 °C using capillary radiant heating. The schematic is shown in Figure 1. This step utilization of geothermal energy at various temperatures on the end product can increase the utilization of geothermal energy, but even capillary radiant heating can only use thermal energy of about 28 °C, or it will cause the return water temperature to be too high, resulting in resources waste.

4.3. Plate heat exchanger + water source heat pump

Plate heat exchanger + water source heat pump is a common way in the use of geothermal cascades. The water source heat pump technology is used to upgrade the thermal energy grade of the ground temperature tail water in the system to realize the geothermal cascade utilization. The schematic is shown in Figure 1.

In the literature[9], a building uses a plate replacement + water source heat pump cascade utilization system. Because of the ground temperature floor radiant heating, the primary and secondary plates are replaced by the secondary side of the effluent to directly heat the building, so that the ground is 30-60 °C. The hot water resources are effectively utilized, and compared with the amount of geothermal water extraction, the amount of geothermal water extracted by the four-stage heat exchange heating with the water source heat pump is only 1/3 of that of the primary plate exchange and the secondary plate replacement. 1/2.

4.4. Plate heat exchanger + absorption heat pump

In addition to the use of water source heat pump technology, the geothermal cascade technology can also adopt absorption heat pump technology, which is a heat recovery equipment that uses heat energy as the main driving energy. It mainly uses liquid refrigerant to absorb and cool the refrigerant at low temperature and low pressure. The thermal load, which is produced by the cooling effect[10], is a new direction of current geothermal development and utilization. The advantage of using an absorption heat pump in geothermal cascade utilization is that the absorption heat pump unit can reduce the return water temperature of the primary network, greatly reduce the irreversible loss during the heat exchange process[11], save investment in the pipe network, improve product efficiency, and improve energy.
Utilization rate. The disadvantage is that the service life is short, the power saving is not energy-saving, and the thermal coefficient is low, generally 0.4-2. The schematic diagram is shown in Figure 2.

![Figure 2. Heat exchanger + absorption heat pump cascade utilization system](image)

5. New rural cascade utilization system

Based on the actual project of Daying Town in Xiong'an New District, this paper proposes a new rural geothermal cascade utilization system as shown in Figure 3. The project has drilled 19 geothermal wells (including 12 eyes and 7 recharge wells); 6 heat exchange stations, each with a construction area of about 300 square meters; and a pipe network of about 400 kilometers. After the project is implemented, the total heating capacity is 700,000 ㎡, which can solve the problem of clean heating in the winter of more than 5,000 villagers in 10 natural villages in Daying Town. It uses medium-deep layer hydrothermal geothermal energy as a heat source.

![Figure 3. New rural geothermal cascade utilization system](image)

The system uses a radiator to heat the heating when the fluid temperature is 35-60 °C. At 25-35 °C, the ground tube is used for heating, and then the tail water at 25 °C is exchanged for heat exchange to the domestic hot water plate to 21 °C. The hot water storage tank is provided to the farmers for domestic water after being heated by the auxiliary heat source. The temperature of the recharged tail water is 25 °C. This system can be freely changed according to the user's hot water temperature demand. This form of utilization is calculated according to the following formula:

\[
\eta = \frac{Q_s}{Q_{\text{max}}} = \frac{t_1 - t_2}{t_1 - t_0} \tag{1}
\]

In the formula,
- \(\eta\) — Geothermal utilization;
- \(Q_s\) — Geothermal actual heat utilization (kW);
- \(Q_{\text{max}}\) — Geothermal maximum available heat (kW);
$t_1$ —— Geothermal stable flow temperature (°C);
$t_2$ —— Geothermal fluid discharge temperature (°C);
$t_0$ —— Local annual average temperature (°C).

The annual average temperature in this area is 11.7 °C, and the geothermal utilization rate of this method is calculated to be 77%.

If the above-mentioned geothermal cascade utilization method is used for cost estimation, if the heating area is 100 ㎡, only the plate heat exchanger is used for the step utilization. a total of about 26,500 yuan, geothermal utilization rate of about 47%, did not reach the standard of 60% of geothermal utilization. If the end-use equipment is used for step-by-step utilization, and the total price of the equipment is about 56,600 yuan. If the plate replacement + water source heat pump is used for step utilization, the total equipment cost is about 120,000 yuan. If a plate replacement + absorption heat pump is used, the total price of the equipment is about 80,000 yuan. If a new cascade utilization system is used, the total price of the equipment is about 32,500 yuan. Up to about 60% cost would be saved. Take the use of ground source heat pump for cascade utilization as an example, and the simple economics of the new system are shown in Table 2.

Table 2. Comparison of new utilization system and ground source heat pump cascade utilization system

| System form                                      | Initial investment /㎡ | Operating expenses /100 ㎡/year | Crude calculation static payback period(year) |
|-------------------------------------------------|------------------------|-------------------------------|---------------------------------------------|
| New cascade utilization system                   | About 350 yuan         | About 3000 yuan               | 5                                           |
| Ground source heat pump cascade utilization     | About 1200 yuan        | About 10000 yuan              | 8.45                                        |

It can be seen that the initial investment and operating cost of this new system is significantly lower than that of the ground source heat pump cascade utilization system, which can meet both high utilization rate and low cost.

6. Conclusion
Geothermal cascade utilization is a very effective way to fully utilize geothermal energy. In practical applications, different cascade utilization schemes can be formulated according to the outlet water temperature, water volume, and site specific conditions. This new geothermal cascade utilization system utilizes the radiator + floor heating end, combined with the domestic hot water plate replacement + hot water storage tank and auxiliary heat source to enable geothermal energy to achieve high utilization under low cost conditions, thereby enabling geothermal utilization in rural areas more efficient.

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