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A STUDY ON SELECTING OPTIMUM OPERATION MODE FOR A HYBRID GEOTHERMAL AND SOLAR POWER GENERATION SYSTEM

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ABSTRACT

A new hybrid model of geothermal-solar power generation system has been investigated in this study with particular reference to the utilization of Hot Dry Rock (HDR) geothermal energy which usually associated with the application of enhanced geothermal system (EGS) technology. But long-term extraction of geofluid from the HDR could cause a considerable thermal energy depletion near the production zone, resulting in a decrease of the geofluid temperature. The hybrid system presented here is aimed at using solar energy to avoid continuously extracting too much geofluid in order to mitigate the thermal depletion circumstances. This hybrid system is designed as a power cycle with two interactive heat sources (geothermal and solar energy), which could generate the rated power of 1MW all the time by letting the two heat sources (two vaporizers) operation in different ways. The numerical simulation and optimization of different operation strategies under different solar conditions have been carried out. Organic Rankine cycle (ORC) is used for power generation. The total power output is controlled by adjusting the order in which the working fluid flows through the two vaporizers. The heating system in parallel mode as well as in series mode have been investigated. Results shows that, in the subcritical cycle scenario, the two vaporizers in series (with geothermal heating first) has a better performance. Whereas, in the transcritical cycle scenario, the two vaporizers in parallel has a better performance.

Keywords: Geothermal-solar hybrid system; Enhanced geothermal system (EGS); Organic Rankine cycle (ORC); Optimum operation mode.

1. INTRODUCTION

In recent years, the research on enhanced geothermal system (EGS) is popular. But so far there is only one commercially operated EGS power station in the Soultz region of France [1]. Hydrothermal natural convection geothermal flashing evaporation power generation has experienced a long period of practical application. Wairakei, New Zealand, geothermal power station has been running for nearly 60 years [2]. However, most of geothermal resources in China are HDR with very little water and even no water. HDR is distinguished from hydrothermal geothermal field. Since the heat transfer of solid rock has no convective heat transfer, only heat conduction. The rate of heat conduction is much less than convective heat transfer, continuous heat extraction will cause local heat depletion, affecting the subsequent power output. The defect of solar power generation is intermittent. Therefore, it is necessary to apply the hybrid of geothermal energy and solar energy to overcome these defects.

Many studies have been carried out on the hybrid of the geothermal energy and solar energy generation. Ö. Çağlan Kuyumcu et al. [3] and Cheng Zhou et al [4] pointed out that the effect of summer ambient temperature rise on ORC cooling is approximately 70%. To eliminate this effect, the hybrid of geothermal energy and solar energy is proposed. Li Kewen et al. [5] pointed out that solar thermal is more suitable than photovoltaic to hybrid with geothermal. Aysegul Turan et al. [6] calculated the annual power output of the hybrid power plant based on Turkish geothermal energy and solar energy data, and converted it into reduction of natural gas consumption and carbon emissions; Hadi

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Ghasemi et al. [7]pointed out that the hybrid of geothermal and solar power generation can generate more electricity than the sum of their separate; Marco Cheng Zhou [8] studied the difference between subcritical and supercritical ORC cycles in the hybrid of geothermal and solar power generation.

Almost no previous research considered that the long-term extraction of geofluid from the HRD could cause a considerable thermal energy depletion near the production zone, resulting in a decrease of the geofluid temperature. On the other hand, due to the unsteady solar energy supply, a pure solar power station has difficulty to generate constant electricity having a negative impact on the grid caused by power swing. Therefore, a hybrid system combining the geothermal and solar energy could be an ideal solution for generating a rated net power without power grid load regulation.

In this paper, we will establish and investigate such a hybrid power generation system. According to Olasolo et al.[9], there are plenty of HDR geothermal resources which come to around 500 Exajoules per annum. Using just 1% of this amount to meet global energy needs would provide us with all the energy that the planet requires for 2800 years at a constant consumption rate. Thus this study is considered necessary and useful in terms of applied energy.

2. SYSTEM DESCRIPTION

The hybrid of geothermal and solar power generation system schematic diagram is shown in Figure 1. The blue part is the geothermal water circulation system, the red part is the solar heating system, the black part is the ORC power generation cycle, and the green part is the cooling system. An electric fan driven air cooling system will be used in areas where water is scarce. Valves 1-7 control the flow of the working fluid through the heater to adjust the production mode. Valves 1 and 2 are flow rate control valves that can control the flow rate to distribute the working fluid entering the two heating systems.

The power station site selected in this paper is the Gonghe region in Qinghai Province, China, where there are abundant geothermal and solar energies. According to Si Yang [10], the HDR temperature at the depth of 3705 meters is 236 °C. Based on this, the wellhead temperature and pressure were assumed as 185 °C and 3 MPa respectively in this study.

In the geothermal water circulation system (in blue color, Fig.1), geothermal water is produced from the production well, and after the pressure is stabilized by the water pump, it enters the heat exchanger, releases heat to the working fluid, and then flows back into the injection well. In the solar heating system (in red color), the solar heat collector uses a parabolic concave concentrating heat collector to heating the heat transfer oil, and then the heat transfer oil enters the heat exchanger to transfer heat to the working fluid, and then completes the circulation through the pump to accomplish continuous heat collection. The use of an air cooling system (in green color) is assumed because of the shortage of water in the Gonghe region.

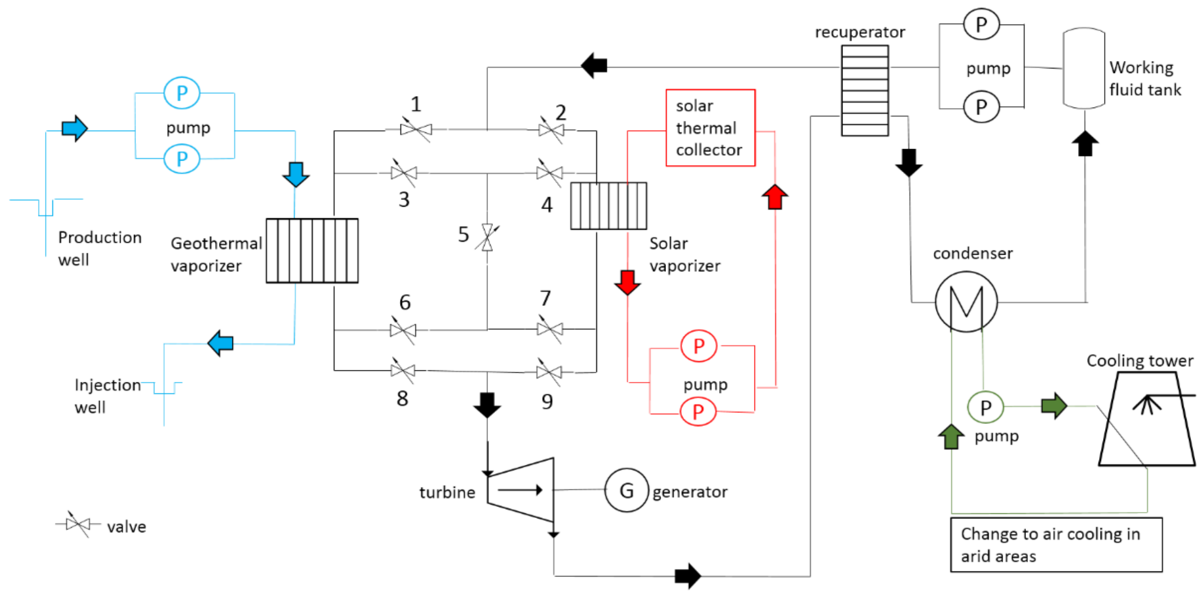

Fig 1 Schematic diagrams of the hybrid of geothermal and solar power generation

In the ORC cycle (in black color), R245fa is chosen as the working fluid for this study because it is safe, stable, non-flammable and low-toxic. The working fluid is pressurized by the pump, passes through the regenerator, and then is evaporated. When the valves 3, 4, 5, 6, 7 are closed, and the rest are opened, the two sets of heating systems are operation in parallel, the working fluids are respectively heated to the same state and mixed, the mixture enters the turbine and expands to generate electricity. The ratio of the working fluid entering the two heating systems is determined by adjusting the opening degree of the valves 1, 2. When the valves 1, 4, 5, 6, 9 are opened, and the others is closed, all the working fluids first flow through the geothermal heating system, then enter the solar heating system, and finally enter the turbine. When the valves 2, 3, 5, 7, 8 are opened and the others are closed, all of the working fluids flow through the solar heating system first, then enters the geothermal heating system, and finally enters the turbine. After the working fluid is expanded in the turbine, it flows through the recuperator and then condenses to become liquid state, completing the cycle. Figure 2 shows the temperature-entropy (T-s) diagrams of of power cycles with consideration of five different heating modes.

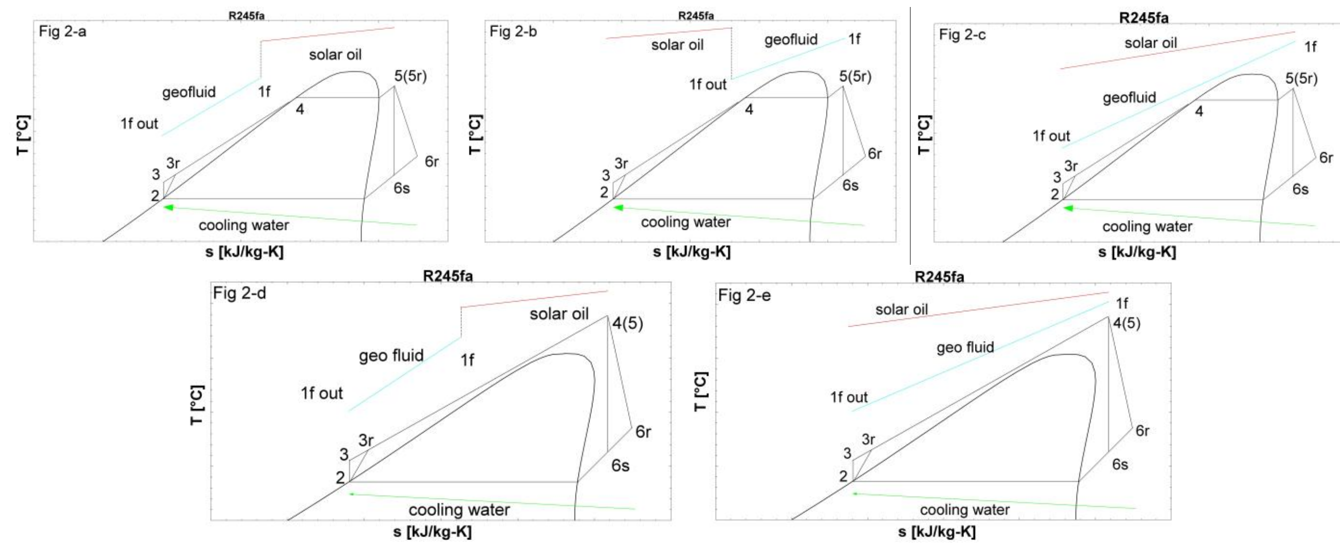

Fig 2 Temperature-entropy diagrams of power cycles with consideration of five different heating modes:

(a) The two vaporizers in series with geothermal heating first (subcritical cycle)
(b) The two vaporizers in series with solar heating first (subcritical cycle)
(c) The two vaporizers in parallel (subcritical cycle)
(d) The two vaporizers in series with geothermal heating first (transcritical cycle)
(e) The two vaporizers in parallel (transcritical cycle)

3. METHODOLOGY

A According to the power generation system described in last section, the rated net power output of the power plant was set to be 1MW, including the auxiliary power consumption such as working fluid pumps, cooling water pumps and air cooling fans.

In the system optimization, the specific net power output (net electricity, in kWh, generated per kg of geofluid) was chosen as objective function. The maximum specific net power output corresponds to the minimum consumption of geofluids for a given power output.

The thermodynamic model of this hybrid system was set up using Engineering Equations Solver (EES: Academic Professional Academic Professional V10.488-3D [2018-08-30]) [11].

The evaporation temperature of the ORC is optimized first under the given geothermal conditions. Then the area of the solar energy collector required for running the ORC plant solely for the rated net power output is determined under the peak solar radiation condition. Then change the solar radiation intensity and calculate geofluid consumption (mass flowrate) with the solar radiation intensity ranging from zero to the peak value. The geofluid consumption of the different operation modes under a given solar radiation intensity is compared to select the best operation mode. Similar optimization process was used for the transcritical power cycle scenarios. In this study, the peak value of DNI (direct normal irradiance) was selected as 2kW/m^2 according to the data of the weather bureau.

4. RESULTS AND DISCUSSION

4.1 Optimization of subcritical power cycles

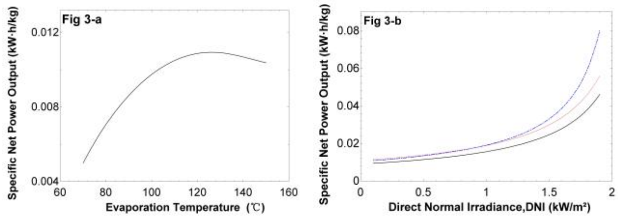

Fig.3 Optimization results of the subcritical power cycles.

(a) Calculation results for determining optimum evaporation temperature

(b) Calculation results for determining the optimum heating arrangement of the two vaporizers. Blue: in series with geothermal heating first. Red: in parallel. Black: in series with solar heating first.

It can be seen from the Fig.3(a) that the specific net power output (net electricity, in kWh, generated per kg of geofluid) has a highest value when the evaporation temperature is 130 °C. Under this condition with the injection temperature of 78.54 °C, the total power generation is 1316kW, and the corresponding auxiliary power consumption is 316KW, which is about 24% of the total power generation. Given this, the required areas of the solar heating collector is calculated and found to be 14443 m^2.

Fig.3(b) shows the specific net power outputs of the three heating modes (arrangement of the two vaporizers) with respect to the solar direct normal irradiance (DNI). It can be seen that when the value of DNI is high, the two vaporizers in series with geothermal heating first (blue curve) has a better performance, especially when the NDI is greater than 1.3kW/m^2. Under the condition that the value of DNI is lower than 1 kW/m^2, the two vaporizers in parallel operation (red curve) has about the same performance as that in series with geothermal heating first. Under any solar radiation condition, the heating mode in series with solar heating first (black curve) has a lowest specific net power output.

4.2 Optimization of *transcritical power cycles*

The transcritical power generation scenarios, shown in Fig.2 (d) and (e), have also investigated. The vaporizer's evaporation pressure and its outlet temperature of the working fluid are optimized. The higher the vaporizer's outlet temperature, the more power generated. However, the vaporizer's outlet temperature is subject to the wellhead geofluid's temperature (185°C). In this study, the vaporizer's outlet temperature was chosen to be 180°C. Fig.4(a) shows the relationship between evaporation pressure and the specific net power output. As can be seen, the optimum evaporation pressure is found to be 3.8 MPa.

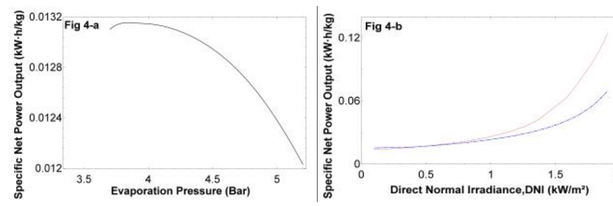

Fig.4 Optimization results of the transcritical power cycles.

(a) Calculation results for determining optimum evaporation temperature

(b) Calculation results for determining the optimum heating arrangement of the two vaporizers. Red: in parallel. Black: in series with geothermal heating first.

Fig.4(b) shows the optimization results for the two transcritical scenarios, corresponding to Fig.2 (d) and (e).

As can be seen in Fig.4(b), contrary to the subcritical cycle scenario, the two vaporizers in parallel operation (red curve) has a better performance when the value of DNI is high, especially when the DNI is greater than 0.8kW/m^2. There is no big difference between the two heating modes when the value of DNI is low.

The results obtained in this study can be applied to any Hot Dry Rock (HDR) geothermal resources. Although this research is based on 1MW installed capacity, the results can be used for large-scale applications.

5. CONCLUSIONS

This paper investigated a hybrid power generation system using the hot dry rock geothermal energy and solar energy, with particular reference to the investigation of the operation modes of the two vaporizers. Different heating modes in both subcritical cycle and transcritical cycle scenarios have been analyzed. The following conclusions can be drawn from the study:

1) The basic ORC cycle is optimized under the given geothermal resource condition. For generating the rated power of 1MW, the optimal evaporation

temperature is obtained, based on which the corresponding parameters of the ORC cycle as well as the solar heating collector area are determined.
2) In the subcritical cycle scenario, the heating mode with the two vaporizers in series (with geothermal heating first) has a better performance.
3) In the transcritical cycle scenario, the heating mode the two vaporizers in parallel operation has a better performance.

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