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A Novel Type of Hot Dry Rock Power Generation System

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ABSTRACT

To improve the utilization of hot dry rock resources, a novel type of hot dry rock power generation system is proposed in this paper. In this system, the Kalina system is coupled with the organic Rankine cycle (ORC) system. Combined with the operating parameters of the geothermal power generation project in Husavik, Iceland, the cycle performance of the novel power generation system and the conventional Kalina system is compared and analyzed by the Engineering Equation Solver (EES) software. The results show that (1) under the same heat source conditions, the net power generation of the novel power generation system is higher than that of the conventional Kalina system, and as the proportion of preheating increases, the net power generation increases by 38%-46%. (2) When the cooling water temperature increases from 5°C to 30°C, the net power generation of the system is reduced by 1089 kW, and the power generation ratio of the ORC system is always maintained at approximately 30%. (3) There is an optimal ORC subsystem evaporation temperature of 56°C so that the net power generation of the entire system reaches a maximum of 3088 kW.

Keywords: Hot Dry Rock, Kalina, ORC, Power generation system, Net power generation

1. INTRODUCTION

China is rich in hot dry rock resources, so the next major task is to study the power generation cycle technology that matches the hot dry rock resources. The Kalina cycle has been extensively studied due to the advantages of the variable temperature and phase change characteristics of the ammonia working fluid.

To improve the performance of the Kalina cycle, many scholars have improved the structure of the Kalina cycle system. Xu [1] proposed the absorption power and refrigeration combined cycle and studied the thermal performance. Wu [2] and Zheng [3] analyzed some combined cycles based on the Kalina cycle with an ammonia-water mixture as the working medium. Liu [4] proposed a novel power and refrigeration combined cycle and analyzed and optimized it using thermal efficiency and exergetic efficiency as indicators. Liu [5] optimized the ammonia absorption refrigeration system using the pinch analysis method and pointed out that the performance coefficient increased by 11.58%. Yue et al. [6] proposed the Kalina system for one-time pumping heat recovery and staged pumping and discussed it from the perspective of thermodynamics. Lu [7] combined the basic Kalina cycle with the second type of absorption heat pump and proposed the double absorption Kalina cycle.

Based on the abovementioned scholars' research on the Kalina system, this paper proposes a new type of hot dry rock power generation system that couples the Kalina cycle system and the ORC power generation system. The net power generation of the system is used as an indicator to analyze the influence of the preheating proportion, cooling water temperature and evaporation temperature of the ORC subsystem on the new system.

2. SYSTEM DESCRIPTION AND MATHEMATICAL MODEL

2.1 System description

The novel power generation cycle is shown in Figure 1.

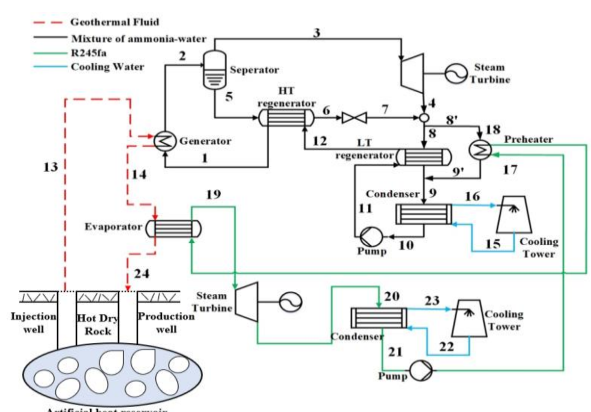

Fig.1 Diagram of the novel hot dry rock power generation system

There are two aspects to the advantages of the novel hot dry rock power generation system. First, the coupled ORC power generation system can further utilize the remaining energy in the geothermal tail water discharged from the Kalina system, reduce the return temperature of the geothermal water, and improve energy utilization. Second, the ORC working medium is preheated by using the heat of the Kalina system steam turbine exhaust gas through the parallel preheater, which not only increases the working medium temperature at the inlet of the ORC subsystem evaporator but also improves the power generation efficiency of the ORC system. At the same time, the enthalpy of the ammonia-water mixture is reduced after power generation, thereby reducing the power consumption of the Karina cooling system.

2.2 Mathematical model

To make the simulation results more comparable and to better verify the correctness of the simulation results and the program, this paper refers to the actual operating parameters of the Kalina geothermal power plant and the working conditions in reference [8] for simulation calculations. The system input parameters are shown in Table 1. To simplify the calculation, this paper makes the following assumptions.

(1) The power generation cycle system is always operating in a stable state.

(2) Steam turbines and working fluid pumps have isentropic efficiency.

(3) There is no pressure loss along the pipeline.

Tab. 1 Input parameters of the new generation cycle

Project	Value	Project	Value
Temperature of geothermal water/℃	122	Turbine inlet pressure/bar	32.3
Temperature of Kalina cycle tail water/℃	80	Steam turbine isentropic efficiency	0.87
Temperature of final tail water/℃	60	Generator efficiency	0.96
Cooling water inlet temperature/℃	5	Isentropic efficiency of working fluid pump	0.98
Mass flow of geothermal water/kg/s	89	Pump efficiency	0.75
Ammonia content of basic solution	0.82	Heat exchanger pressure loss/bar	1

Among them, the outlet temperature of the ammonia-water mixture and the ORC working medium in the condenser is determined by the condensation temperature, and the evaporation pressure of the evaporator is determined by the pressure of the working medium pump.

3. SYSTEM RESULTS AND DISCUSSION

3.1 Model validation

The calculation results of the original Kalina cycle model established in this paper were compared with the data in reference [8], and the results show that the simulation results are basically consistent with the calculation results in the reference, thus verifying the correctness of the model and the rationality of the parameter assumptions, as shown in Table 2.

Tab. 2 Performance parameter comparison

Parameter	Values in references	Simulation results (without considering cooling work)	Simulation results (considering cooling work)
Heat release power of geothermal water/kW	15700	15709	15709
Power generation/kW	2180	2217	2217
Net power generation/kW	2104	2141	1988
Working fluid pump power consumption/kW	76	76	76
Cooling system power consumption/kW	—	—	153
Cycle efficiency/%	13.4	13.5	12.7

3.2 Result analysis

3.2.1 Performance comparison between the novel power generation system and the Kalina system

Table 3 is a comparison table of performance parameters between the novel power generation system and the Kalina system. According to the simulation results, the temperature at the outlet (state point 8) of the mixer is 46°C. When the minimum heat transfer temperature difference of the preheater is 6°C, the outlet temperature of the preheater is the highest; at this time, the preheating proportion is 0.35. Since the inlet temperature of the evaporator is 80°C and the outlet temperature is 60°C, the evaporation temperature is 70°C and the ORC working medium is R245fa.

Tab. 3 Comparison table of performance parameters

Parameter	Kalina system	New system (preheating proportion is 0)	New system (preheating proportion is 0.35)
Heat release power of geothermal water/kW	15709	23240	23240
Power generation/kW	2217	3041	3206
Net power generation/kW	1988	2745	2911
Working fluid pump power consumption/kW	76	92	95
Cooling system power consumption/kW	153	204	200
Cycle efficiency/%	12.7	11.8	12.5

By comparing the output power of the Kalina power generation system and the novel hot dry rock power generation system, it is observed that under the same conditions, the total output power of the novel power generation system is higher than that of the Kalina system. When the preheating proportion is 0, total output power increases by 824 kW, which is approximately 37%. The net generation power increased by 757 kW, approximately 38%. When the preheating proportion was 0.35, it increased by 989 kW, approximately 45%. The net generation power increased by 953 kW, approximately 46%. This is because the Kalina cycle power generation system only uses geothermal water from 122 ℃ to 80 ℃, and the novel power generation system uses the heat of geothermal water from 122 ℃ to 60 ℃ and uses the heat of the steam turbine exhaust in the Kalina system to preheat the condensed ORC working medium, which improves the inlet temperature of the evaporator and further increases the power generation of the novel power generation system.

3.2.2 Effect of cooling water temperature

This section studies the effect of cooling water temperature on the thermal performance of the novel power generation system under the conditions of a preheating proportion of 0.35 and an evaporation temperature of 70°C. The results are shown in Figure 2.

Figure 2 shows that the net power generation of the novel power generation system decreases with increasing cooling water temperature. When the cooling water temperature increases from 5℃ to 30℃, the total net power generation of the system drops from 2911 kW to 1822 kW, a decrease of approximately 62.5%. However, with the increase in the cooling water temperature, the net power generation of the ORC system changes little in proportion to the entire system, which is always maintained at approximately 30%. This indicates that the impact of the cooling water temperature change on the ORC system and the entire novel power generation system is positively correlated, and the system coupled with the ORC is still suitable for the new power generation environment.

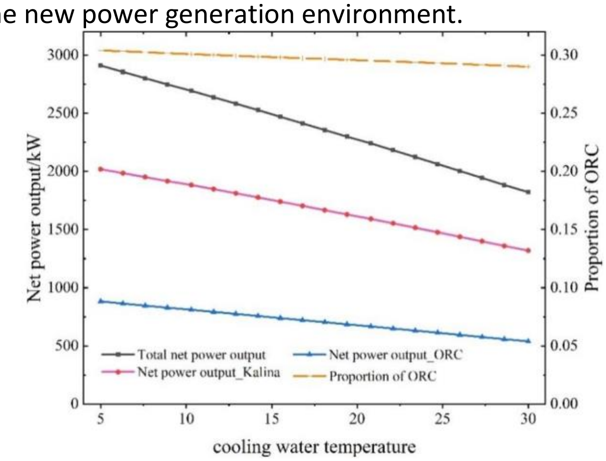

Fig.2 Effect of the cooling water temperature on system power generation

3.2.3 *Effect of the final tail water temperature*

In this section, to study the influence of geothermal tail water temperature on the novel power generation system, the geothermal final tail water temperature of 50℃-60℃ is simulated under the condition that the preheating proportion is 0.35 and the cooling water temperature is 5℃ (50℃ can meet the temperature demand of heating in bad weather), and the results are shown in Figure 3.

It can be obtained from Figure 3 that when the temperature of the final tail water decreases from 60℃ to 50℃, the net power generation of the system increases from 2911kW to 3276kW, an increase of about 12.5%. This is because as the temperature of the geothermal tail water decreases, the ORC system can take more heat from the geothermal water for power generation, so the power generation of the system increases and the net power generation also increases. However, for the cycle efficiency of the system, it can be seen that the cycle efficiency of the system decreases from 12.5% to 12.1% when the geothermal tail water decreases from 60℃ to 50℃. This is due to the decrease of the final tail water temperature, resulting in the increase of the total heat available for the novel power generation system. The increase of power generation only depends on ORC system, which leads to the increase of net power generation of the system is much less than the increase of total heat of geothermal water, and finally leads to the reduction of cycle efficiency of the system.

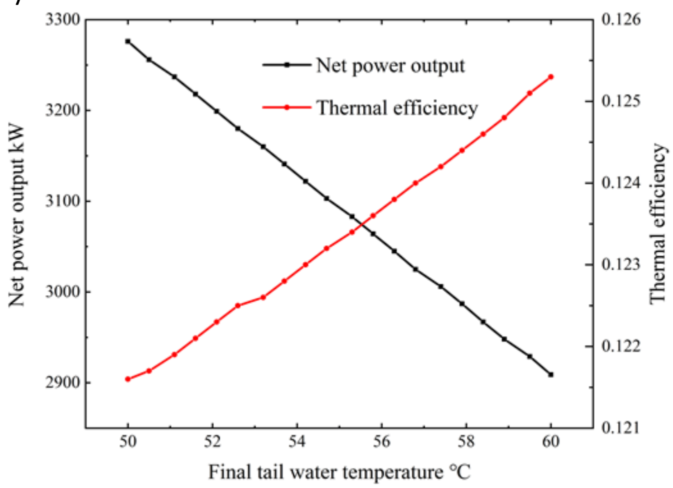

Fig.3 Effect of final tailwater temperature on system performance

In summary, the optimal operating conditions of the novel power generation system can be obtained according to the operating optimization results of various operating parameters, and the results are shown in Table 4.

Tab. 4 The best operating condition table of the novel power generation system

Item	Parameter
Proportion of preheater	0.35
Cooling water temperature/℃	5
Final tail water temperature/℃	50
Maximum net power generation/kW	3276

4. CONCLUSION

To improve the utilization rate of hot dry rock resources, this paper proposes a new type of hot dry rock power generation system that couples the Kalina system and the ORC system. At the same time, using the net power generation of the system as an indicator, the cooling water temperature and evaporation temperature of the ORC subsystem are thermodynamically optimized, and the following conclusions are obtained:

(1) Under the same heat source conditions and operating parameters, the net power generation of the novel hot dry rock power generation system is higher than that of the Kalina system, the cycle efficiency is not much different, and the cycle efficiency has little difference.

(2) With increasing cooling water temperature, the net power generation and cycle efficiency of the new generation system decrease. When the cooling water temperature increases from 5°C to 30°C, the net power generation drops from 2911 kW to 1822 kW, the cycle efficiency drops from 12.5% to 7.8%. However, the power generated by the ORC system accounts for approximately 30% of the total power of the novel power generation system, and the ORC subsystem’s power generation contribution is still relatively large.

(3) When the preheating proportion is 0.35 and the cooling water temperature is 5℃, there is a final tail water temperature of 50℃, which makes the net power generation of the entire novel power generation system take the maximum value of 3276 kW. Compared with the conventional Kalina power generation system, setting the final tail water temperature to 50℃ can increase the net power generation by approximately 1288 kW, an increase of approximately 65%.

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