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Thermodynamic analysis of a power and water combined system with geothermal energy utilization

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ABSTRACT

A novel combined system, integrated with a flashing Ranking cycle and humidification dehumidification (HDH) desalination unit, is proposed to achieve the energy utilization from geothermal water. The flashed steam is used to generate power while the remaining water is applied to heat the seawater for water production. Based on the coupling relation between the power and desalination unit, conservation equations based on the thermodynamic laws are constituted. Energy and entropy analysis of the combined system are achieved for determining the power and water production. Furthermore, the influence principles from the spraying temperature and terminal temperature difference of the seawater heater on the overall performance of the combined system are also focused. The simulation results indicate that the maximal net power from the flashing Rankine cycle reaches 157.0 kW when the flashing temperature is 375.15 K. Due to the leading role to determine total efficiency of the combined system, maximum values of 711.85 $kg\,h^{-1}$ for the water production and 43.98% for the total efficiency are obtained when the flashing temperature is 378.15 K. Furthermore, it is also obtained that a lower value both for the seawater spraying temperature and terminal temperature difference of the seawater heater can help to improve the performance of the combined system.

1. Introduction

In view of the unsustainable development in the past centuries, the crisis of energy and freshwater are becoming a reality gradually. As a result, energy and water supply with clean and efficient method has attracted more and more attentions. Thereinto, geothermal resources, which mainly contain geothermal dry steam, geothermal wet steam and geothermal water belongs to the renewable energy, and they are first applied investigated and applied to achieve the power generation all over the world (Nian and Cheng, 2018; Sowizdzal, 2018).

Jalilinasrabady et al. (2012) first designed a single flash cycle for power generation with geothermal energy, which has a temperature of 513 K. Based on the developed mathematical models for thermodynamic analysis, it was found that the proposed scheme can obtain a maximum net power output, 31 MW, when the flashing and discharged pressures were fixed at 5.5 bar and 0.3 bar, respectively. For the sake of a optimized energy utilization, a double flash configuration was then advised, and the relevant maximum net power can arrive at 49.7 MW. In combination with the exergy analysis, a double flash cycle system for the Sabalan power plant was finally proposed. Yari (2010) achieved a comparative investigation for different types of geothermal power plant, aiming to high temperature geothermal resources with a temperature of 503 K. Mathematical models for each contained thermal cycle was developed, with model validation by previous published data. After the energy and exergy analysis, the results comparison was completed for clarifying the best cycle configurations. It was found that the thermal efficiency of the binary cycle with a regenerative ORC have the highest efficiency of 15.35%. Wang et al. (2015) introduced a Kalina cycle for further heat recovery of geothermal water from a primary flashing cycle, powered by the geothermal water with a temperature of 443 K. Based on the established mathematical models of the flash-binary geothermal power generation system, the influences from critical thermal parameters are examined, and an optimization method was also proposed to determine the best performance with exergy efficiency as the objective function. It was discovered that the best exergy efficiency of the system can arrive at 37.01% under the prescribed input boundaries. Yang et al. (2017) proposed an organic Rankine cycle to generate power with geothermal resource from abandoned oil wells, with a temperature of 383 K. With R245fa as the cycling working fluid, a four-stage axial turbine was appointed in the ORC, and an onsite test showed that the efficiency of the turbine and entire cycle can reach 78.52% and 5.33%, respectively. The research results and method could

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Nomenclature

Roman symbols

h	enthalpy (kJ kg^{-1})
h_{fg}	latent heat (kJ kg^{-1})
L	length along the heat exchanger (mm)
m	mass flow rate (kg s^{-1})
p	pressure (MPa); wet perimeter (m)
Q	heat load (kW)
RH	relative humidity
s	specific entropy (kJ kg^{-1} K^{-1});
S	concentration of seawater (g kg^{-1}); entropy rate (kJ s^{-1} K^{-1})
T	temperature (K)
W	power (kW)

Greek letters

ε	effectiveness of the humidifier and dehumidifier
ρ	density (kg m^3)
η	efficiency
ω	humidity ratio (g kg^{-1})

Subscripts

a	air
b	brine
c	condenser
d	dehumidifier
da	dry air
e	exhaust
FE	flashing evaporator
fs	flashed steam
fw	flashed water
gen	generation
gw	geothermal water
h	humidifier
i	inlet
m	maximum
o	outlet
p	pump
SH	seawater heater
sw	seawater
t	total
tur	turbine
v	valve
w	water

give some significant references for the desirable power plants with the geothermal energy from the abandoned oil wells.

Based on the aforementioned literature, it can be concluded that the configurations of the power system should be determined by the temperature and components of the geothermal resources (Zheng, 2014; Yao, 2010). For a high temperature geothermal resource, the flashing cycle and low temperature power cycles (Wang et al., 2013; Bahrampoury and Behbahaninia, 2017; Hinze et al., 2017) are always existing simultaneously for the sake of energy cascade utilization. However, in most occasions, power and water are both in rigid demand to satisfy the industrial production and life. Accordingly, in the binary power systems powered by geothermal energy, searching an appropriate desalination method to replace the low temperature power cycle to recover the carried heat of the water from the primary flashing section for water production can achieve the problem. Recent years, the humidification dehumidification methods (Zheng, 2017; Capocelli et al., 2018), which has the great advantages, has been one of the major research focus in the field of desalination.

A saturated air cycling within the HDH desalination unit was assumed to investigate the relevant system performance by Campos et al. (2017). Through the experimental test, the internal parameters were selected to minimize the residual summation of the contained temperature values. Based on the validated the mathematical models, a sensitive analysis from critical parameters on the water production capacity was completed. From the test results, it was observed that the heat load of the solar heater, humidifier height and seawater mass flow rate were the most critical impact factors to change the production, while the influences from the ambient temperature was very slight. Dual solar collectors to heat water and air simultaneously were applied in a HDH desalination system by Rajaseenivasan and Srithar (2017), and the relevant experimental platform was built. After the test, it was found that the mass flow rate and operation temperatures of the working fluid were related to the water producing capacity. An overall efficiency of the system with the concave turbulators arrived at 67.6%. At the aspect of the water production, the highest values reached 12.36, 14.14 and 15.23 kg m^{-2} one day for the schemes without turbulators, convex and concave turbulators, respectively. Siddiqui et al. (2017) studied the performance of an HDH desalination system operated under vacuum environment. Based on the established mathematical models, it was found that the gain output ratio would be raised after decreasing the humidification pressure. Kabeel and Abdelgaied (2018) tested the performance of a HDH system incorporated by an indirect solar dryer. It was discovered that the gain output ratio of the modified system was enlarged by 29%, and it was raised with increasing the air flow rate. In addition of the solar energy, geothermal energy was also used to power the HDH desalination unit by Mohamed and El-Minshawy (2009) and Elminshawy et al. (2016). After the integration between the geothermal resource and HDH desalination unit, the relevant performance was investigated by theoretical and experimental analysis, respectively. In spite of the different effect in each system, the common viewpoint was gained that only the low temperature geothermal resource was suitable for the desalination system.

Due to the absence of the integration between the flashing Rankine cycle and the HDH desalination unit, the present paper focuses on the performance of such combined system for power and water joint production. Based on the thermodynamic laws, the mathematical models of the combined system were built, and then the corresponding energy and entropy analysis for the subsystems and entire system were completed. Furthermore, the influences from the seawater spraying temperature and terminal temperature difference of the seawater heater are also studied. The research results provide significant references for the innovative design and further optimization of the power and water combined systems.

2. System description

The detailed scheme of the novel power and water system, with flashing Rankine cycle and HDH desalination cycle coupled, is exhibited in Fig. 1. Obviously, the power and water supply system consist of the flashing Rankine cycle and HDH desalination cycle. For the aspect of the flashing Rankine cycle, the geothermal water is first pressurized in the pump, and then flows into the flashing evaporator. After the sudden pressure declination, saturated steam is obtained, and then the flashed steam flows into the steam turbine. During the expansion of