A study on the selecting optimum condition and evaporation temperatures for four geothermal power generation systems under different geofluid's conditions

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Abstract

In this study, the optimum flash and evaporation temperatures have been selected for the following four geothermal power generation systems: single-flash system (SF), double-flash system (DF), flash-ORC system (FORC), and double-flash-ORC system (DFORC). The maximum net electricity generated is regarded as an objective function, with the pump and fan consumptions being taken into account. Under the given geofluid's condition (T= 170℃; x= 0.2), the optimum flash temperature of SF, the optimum 2nd-stage flash temperature of DF, the optimum evaporation temperatures of FORC and DFORC are found to be 150℃, 100℃, 100℃, and 70℃, respectively. More geofluid's conditions (T= 80~260 ℃ ; x= 0, 0.2, 0.4) have also been considered for the temperature optimization of each system. The optimization results are shown in Fig.4 which can be useful for engineering application.

Keyword: power, optimum, evaporation

1. Introduction

Geothermal power generation systems usually include single or double flash systems, organic Rankin cycle (ORC) system, or a combination of them. Single-flash system accounted for 43% of the total installed geothermal power capacity in the world [1]. Double-flash system is an upgraded version of the single flash system in order to generate more power [2,3]. ORC system has a better power generation performance for medium-and-low temperature geothermal resources [4-7], and is good at corrosion inhibition [8].

Many studies have been carried out on geothermal power generation systems. As to the single flash system, references [1,9-12] suggested that flash temperature should be the average of geofluid's temperature and condensing temperature. However, references [2, 13, and 14] advised that optimum flash temperature be geometric mean of geofluid's temperature and condensing temperature. As to the double flash system, reference [15] advised that the 1st -stage flasher be just separator (no pressure drop) and the 2 nd -stage flash temperature be optimized to get maximum power output.

Reference [16] advised to get optimum flash temperature by trial method. In reference [3], the 1st-stage flash temperature was equal to the geofluid's, and the optimum 2nd-stage flash temperature was obtained by trial method.

In references [1,17], each stage optimum flash temperature of a multi-stage flash system can be obtained following the philosophy of "equal temperature split". As to the flash-ORC systems, reference [18] studied the effect of flash temperature on flash-ORC systems' thermal efficiency and power output for the geofluid's temperature ranging from 80℃ to 150℃, but the evaporation temperature of this combined systems was not studied. Reference [2] studied energy conversion of single-flash and double-flash systems and advised that plants should choose flash-ORC systems when the geofluid has high temperature and large flux. References [19,20] studied net power output and advised that double-flash systems should be used when geofluid's temperature has a range from 80℃ to 130℃ and flash-ORC systems should be used for the geofluid's temperature ranging from 130℃~150℃.

Reference [13] advised to get optimum flash temperature by trial method for flash-ORC systems. Reference [17] pointed out that the higher the flash temperature; the more power can be generated by steam turbine, but less power by the ORC.

It can be seen that the selecting optimum flash and evaporation temperatures for power generation systems is essential and useful in engineering application. Trial method can be a practical way.

Since geofluid's condition can be different from place to place, it is will be more useful if a wider range of geofluid's condition can be considered in the optimization.

In this paper, we will carry out the temperature optimization through following procedures:

Set up thermodynamic models for four kinds of power generation systems using Engineering Equation Solver (EES). Under the given geofluid's condition (T=170℃; x=0.2), determine the optimum temperatures for each power generation system.

Consider more geofluid's conditions and find the corresponding optimum temperatures for different systems.

2. System description

The schematic diagrams of four geothermal power generation systems in this study are shown in Fig.1. They are single-flash system (SF), double-flash system (DF), flash-ORC system (FORC), and double-flash-ORC system(DFORC).

The temperature-entropy diagrams of SF, DF, and ORC are shown in Fig.2.

The schematic diagram of SF is shown in Fig.1 (a), and its temperature-entropy diagram is shown in Fig.2 (a). Geofluid flows into the separator (flasher) and is separated into liquid and vapor. The vapor flows through the steam turbine to generate power that drives generator. The liquid which remains in the separator is reinjected into the reservoir. The turbine exhaust is directed into the condenser and then reinjected into the reservoir.

The DF has one more flasher (2nd-stage flasher) than the SF, shown in Fig.1 (b). Its temperature-entropy diagram is shown in Fig.2 (b). FORC can be considered as a modified DF system where the 2nd-stage flasher is replaced by an ORC system, shown in Fig.1 (c). Its temperature-entropy diagram is a combination of Fig.2 (a) and Fig.2 (c).

DFORC is a combination of the DF system and an ORC system, with the ORC being analogs to a bottoming cycle, shown in Fig.1 (d). Its temperature-entropy diagram is a combination of Fig.2 (b) and Fig.2 (c).

The working fluid of ORC has a great influence on its thermodynamic performance. Many studies have been carried out for the working fluid selection [21-29].

Reference [24] found that the thermal efficiency of the ORC using R123 was higher than that using R245fa at the same evaporation pressure. Reference [26] also found that the performance of R123 among R236ea, R245fa, R227ea, R600, and R123 was the best for the heat-source temperature ranging from 100℃ to 220℃.

Reference [27] compared some kinds of dry working fluids, and pointed out that using R123 could get the highest thermal efficiency. For the heat-source temperature ranging from 107℃ to 157℃,

Reference [28] stated that using R123 could obtain the highest thermal efficiency. R12, R123, and R134a were also compared in Reference [29], and the researchers found that R123 was the most suitable working fluid in order to get the best thermodynamic performance. For an ORC power generation system, we care about thermal efficiency, net power output, and environmental friendliness. The global warming potential (GWP) value of R123 is just 120.

The ozone depletion potential (ODP) value of R123 is 0.012, much less than 0.05. Also R123 is non-flammable and low-toxic. Due to above reasons, it is necessary to carry out a study on the performance of FORC and DFORC systems using R123 as working fluid.

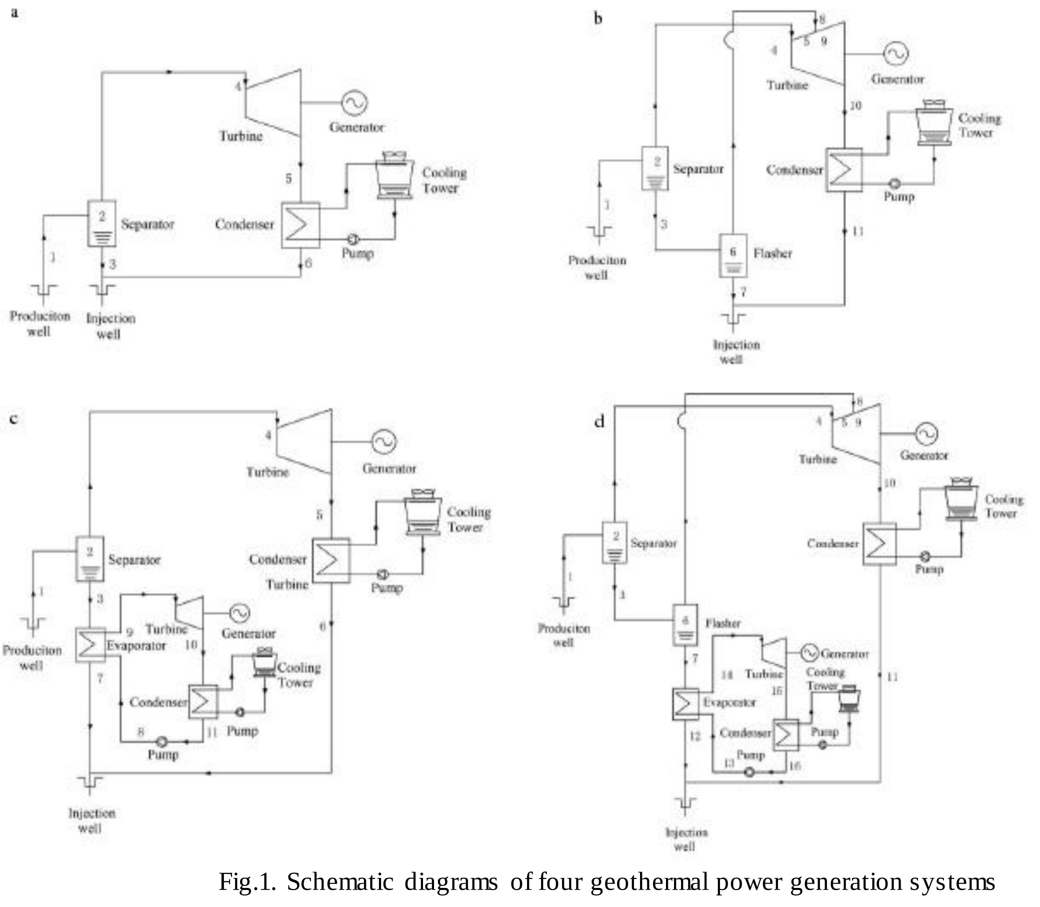

Fig.1. Schematic diagrams of four geothermal power generation systems

(a) schematic diagram of single-flash system(SF); (b) schematic diagram of double-flash system(DF);
(c) schematic diagram of flash-ORC system (FORC); (d) schematic diagram of double-flash-ORC system(DFORC).

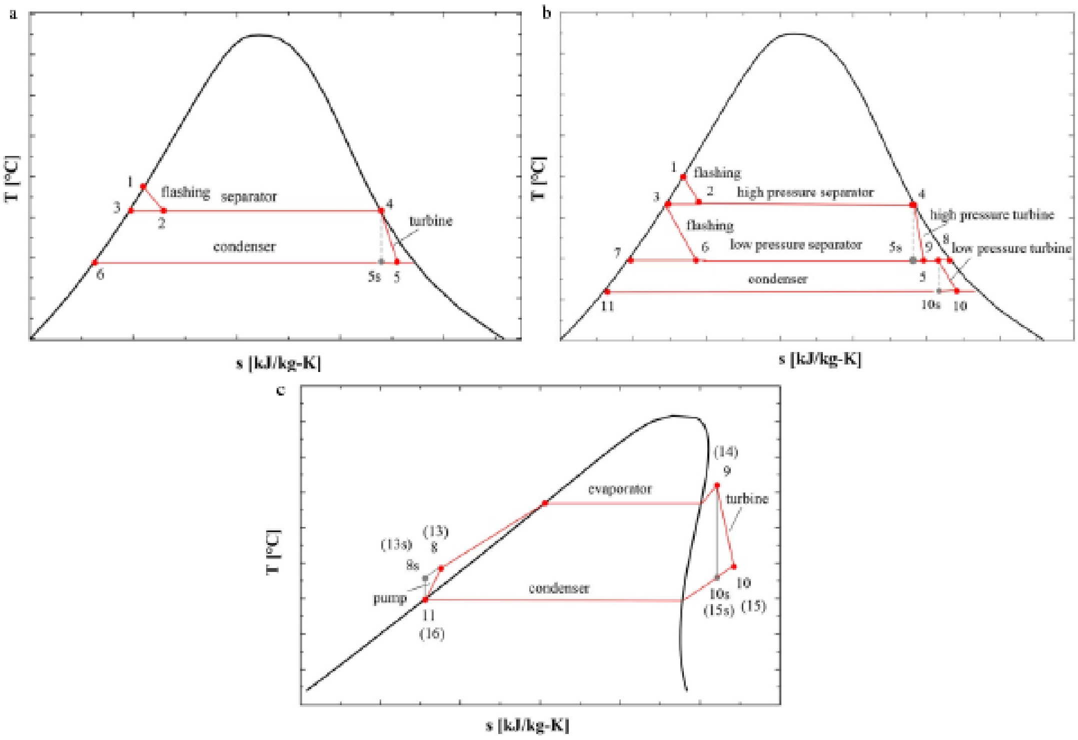

Fig.2. Temperature-Entropy diagrams of four power generation systems
(a) temperature-entropy diagram of SF; (b) temperature-entropy diagram of DF; (c) temperature-entropy diagram of FORC

3. Methodology

As illustrated in Section 2, the combined (or upgraded) power generation systems are based on SF and ORC. In this study we regard net generated electricity as an objective function, taking into account of pump consumption of the whole system and fan consumption of the cooling system.

We get the optimum 2nd-stage flash temperature or evaporation temperature based on the optimized 1st-stage flash temperature. For the DFORC system, we get the optimum evaporation temperature based on the optimized first and second stage temperatures. The net electricity obtained based on this optimization method is greater than those mentioned elsewhere [2, 13, and 14].

The Engineering Equation Solver (EES) has been used for the thermodynamic analysis and the system optimization.

The optimization procedure is as follows:

- Under a given geofluid's condition, the flash temperature of SF was optimized to gain the maximum net electricity. Based on the optimized flash temperature, the 2nd-stage flash temperature of DF as well as the evaporation temperature of FORC was optimized to gain the maximum net electricity. The optimum evaporation temperature of DFORC was then obtained based on the optimized flash temperatures of DF.
- Repeat the above optimization procedure for each of the four systems (SF, DF, FORC and DFORC) under different geofluid's conditions.

Some parameters used in the calculation are listed in the Appendix A. These parameters are based on literatures [30-34] and experimental data.

4. Results

4.1. The optimization of flash and evaporation temperatures under a given geofluid's condition

The optimization of each of the four power systems (SF, DF, FORC and DFORC) has been carried out under the following given geofluid's condition: temperature =170℃, steam dryness = 0.2, and flow rate = 150 t/h .

Fig.3 shows the calculation results of the four power generation systems under the given geofluid's condition.

The relationships of electricity and thermal efficiency versus the flash temperature in SF, the 2nd-stage flash temperature in DF, the evaporation temperature in FORC, and the evaporation temperature in DFORC have been shown in Fig.3 (a), Fig.3 (b), Fig.3 (c), and Fig.3 (d), respectively.

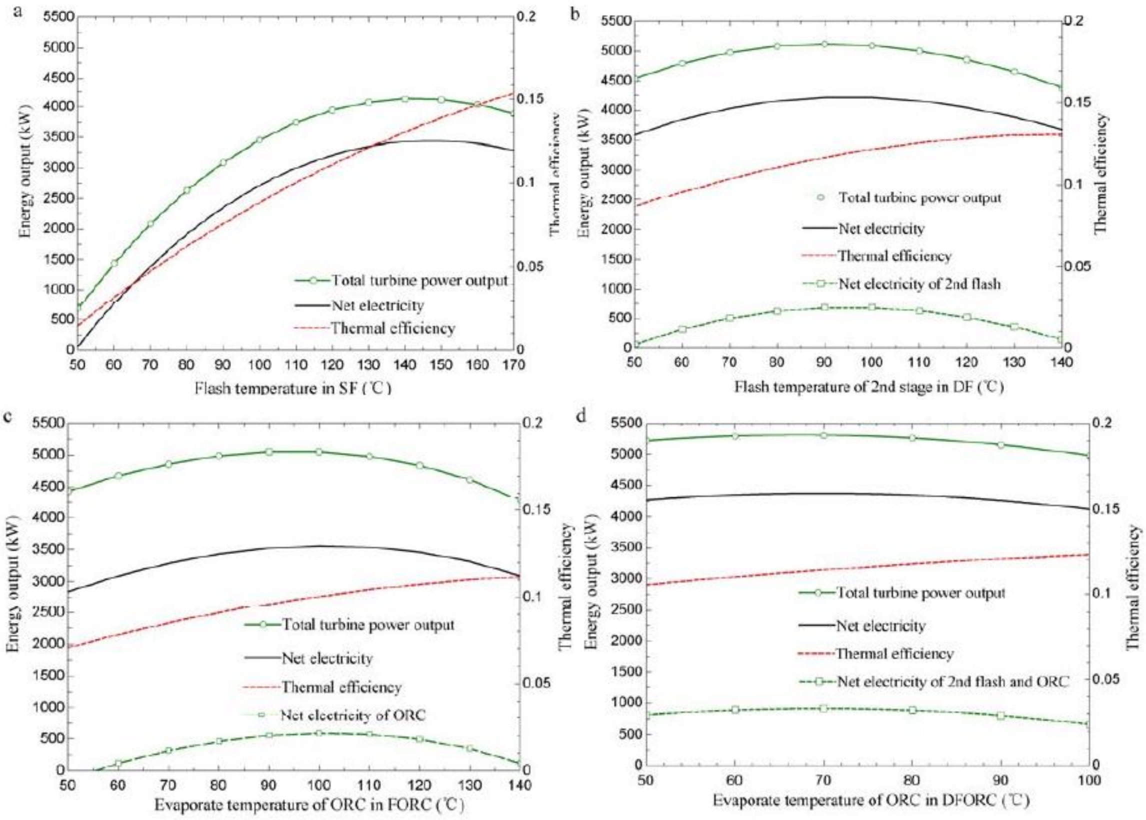

Fig.3. Calculation results for the optimization of flash or evaporation temperatures for four power generation systems in the given geofluid's condition (T= 170℃; x= 0.2)
(a) Calculation results for determining optimum flash temperature of SF; (b) Calculation results for determining optimum 2nd-stage flash temperature of DF;
(c) Calculation results for determining optimum evaporation temperature of FORC; (d) Calculation results for determining optimum evaporation temperature of DFORC.

In Fig.3 (a), the maximum net electricity is 3443 k W corresponding to a flash temperature of 150℃; while the maximum turbine power output corresponds to a flash temperature of 140 ℃. The cause of this difference is due to the consideration of actual power consumption of the cooling system and pumps. Similarly in Fig.3 (b), the maximum net electricity of 4215 k W corresponds to a 2nd-stage flash temperature of 100℃, but in terms of getting a maximum turbine power output, the corresponding optimum 2nd-stage flash temperature is 90℃.
In the Fig.3 (c), the optimum evaporation temperature corresponding to the maximum net electricity of 3563 k W is 100℃; while the optimum evaporation temperature for the maximum total turbine power output is 90 ℃. In Fig.3 (d), the situation is a bit different. Evaporation temperature of 70℃ corresponds to both the maximum net electricity of 4373 k W and the maximum total turbine power output.
We also calculated the thermal efficiencies of the four systems. As can be seen in in Fig.3, the slope of the DFORC thermal efficiency is less than that of the DF system. It is also seen that the thermal efficiency slopes of DF and FORC are much smaller than that of the SF system. This implies that the 1st-stage flash temperature has more influence on the thermal efficiency. It is worth noting that, in each case, the thermal efficiency increases with the increase of flash temperature or evaporation temperature; therefore the optimum flash or evaporation temperature of each system can only be determined based on the net electricity or turbine power output, rather than on the thermal efficiency.

4.2. The optimization of flash and evaporation temperatures under different geofluid's conditions

Fig.4 shows the optimum flash temperature of SF, 2nd-stage flash temperature of DF, and evaporation temperatures of FORC and DFORC under different geofluid's conditions (T= 80~260℃; x= 0, 0.2, 0.4).
The optimum flash and evaporation temperatures increase with the raise of geofluid's temperature. They also increase with the raise of geofluid's dryness, especially when the geofluid's temperature is high. Since the ORC works as a bottoming cycle in the DFORC system, it is not difficult to understand why the optimized evaporation temperature of the ORC has a lower value as shown in Fig.4. The optimum 2nd-stage flash temperature of DF is close to the optimum evaporation temperature of FORC under the same geofluid's condition, especially when the geofluid's temperature is below 170℃ and the dryness is less than 0.2. It is also

noticed that the optimum flash temperature of the SF increases obviously with the raise of the geofluid's temperature and the dryness.

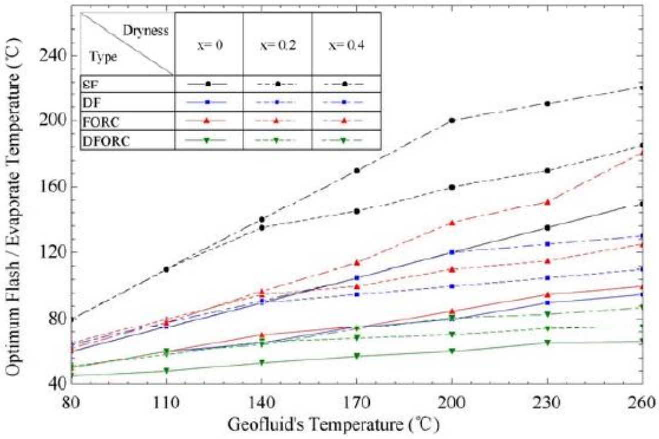

Fig.4. Optimum flash temperature of SF, 2nd-stage flash temperature of DF, and evaporation temperatures of FORC and DFORC under different geofluid's conditions (T= 80~260℃; x= 0, 0.2, 0.4)

5. Conclusion

In this study, selection of optimum flash and evaporation temperatures for four geothermal power generation systems (SF, DF, FORC, and DFORC) has been carried out. The maximum net electricity generated is regarded as an objective function, with the pump and fan consumptions being taken into account.

Under the given geofluid's condition (T= 170℃; x= 0.2), the optimum flash temperature of SF, the optimum 2nd-stage flash temperature of DF, the optimum evaporation temperatures of FORC and DFORC are found to be 150℃, 100℃, 100℃, and 70℃, respectively. More calculations and analysis for determining the optimum flash and evaporation temperatures have been carried out for each power generation system under different geofluid's conditions (T= 80~260℃; x= 0, 0.2, 0.4).

The corresponding results of the optimum flash and evaporation temperatures are shown in Fig.4.

Appendix A. System parameters

Table1. System parameters used in the simulation of the flash and ORC systems.

Items	Parameters
Heat loss in separator or evaporator (%)	3.00
Pressure loss from flasher to turbine (%)	10.00
Turbine isentropic efficiency	0.75
Water turbine isentropic efficiency	0.65
Turbine mechanical efficiency	0.96
Generator efficiency	0.93
Feeding pump isentropic efficiency	0.60
Pressure loss from evaporator to turbine (%)	10.00
Temp. difference at pinch point in evaporator (℃)	6.00
Fan mechanical efficiency	0.75
Density of the air through the fan (kg/m3)	1.20
Inlet temperature of cooling water (℃)	25.00
outlet temperature of cooling water (℃)	35.00
outlet temperature of geofluid from condenser (℃)	40.00
outlet temperature of geofluid from condenser (℃)	40.00

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