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Multi-objective optimization of two double-flash geothermal power plants integrated with absorption heat transformation and water desalination

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ABSTRACT

Two configurations of double-flash geothermal power plants, one is combined with water desalination and one integrated with absorption heat transformation and water desalination, are proposed and investigated from the viewpoint of exergoeconomics. The main purpose of investigated systems is the simultaneous generation of electrical power and distilled water. A three-objective optimization procedure is performed to determine the optimal design points, considering for all configurations the decision parameters to be the pressures of low and high-pressure flash chambers and the temperatures of the evaporator and generator. The optimization aims to minimize the product unit cost, while maximizing the electric power generated and the production rate of distilled water. The Pareto frontiers for each configuration are drawn as part of the procedure. It is shown that, at constant and equal pressures of the high-pressure flash chamber, the product unit cost for the system combined with the absorption heat transformer is the lower of the two systems considered. In addition, under the optimized conditions, the product unit costs are approximately equal for the two studied configurations. However, the value of generated power for the system with an absorption heat transformer is about 17% greater than for the alternate system. Moreover, the system integrated with an absorption heat transformer has higher thermal and exergy efficiencies, at about 20% and 3%, respectively.

1. Introduction

Today, an important factor for economic growth is the availability of electricity. The renewable energy resource, geothermal energy, is used in many countries for electricity generation (Nasruddin et al., 2016). Recently, global geothermal energy use has increased at an approximate rate of 4–5% annually (Paoletti et al., 2015). Since the first dry geothermal power plant was constructed in 1904, various systems for geothermal power have been proposed for converting geothermal to electrical energy (Dipippo, 2008). Considering problems associated with dry systems (Zarrouk and Purnanto, 2015), studies on many other geothermal power system types have been carried out. Guzovic et al. (Guzovic et al., 2012) investigated a geothermal power plant with binary flash that uses a medium-temperature geothermal resource. They coupled the geothermal system with and a Kalina cycle and an organic Rankine cycle (ORC), and compared the thermal efficiencies. Pambudi et al. (2015) proposed double-flash system design and contrasted it with a single-flash power plant using waste brine from a high pressure separator, in Dieng, Indonesia. Sarr et al. (Sarr and Mathieu-Potvin, 2015) proposed double-flash power plants (six variations), and analyzed and optimized the proposed systems and compared them to an optimized double-flash power plant that serves as a reference. Ghasemi et al. (2014) modeled for an ORC operating with geothermal brine at low temperature. The model was validated with 7200 operation data points gathered over a year. The model also was integrated with a solar energy system at low temperature This hybrid system exhibited a higher second-law efficiency than separate geothermal or solar energy systems. Since higher temperature geothermal sources are not sufficiently hot to evaporate much water for purposes of power generation, they are mostly utilized in flash cycles. On the other hand, binary cycles use geothermal sources at lower temperatures

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Nomenclature

Abs	absorber
AHT	absorption heat transformer
c	cost per exergy unit (\$/kg and \$/GJ)
C	cost rate (\$/hr)
Con	condenser
Config	configuration
CRF	capital recovery factor
e	specific exergy (kJ/kg)
EES	Engineering Equation Solver
Eva	evaporator
Ex	exergy rate (kW)
f	thermoeconomic factor
GA	generator assembly
Gen	generator
h	specific enthalpy (kJ/kg)
HFC	high-pressure flash chamber
HPT	high-pressure turbine
HX	heat exchanger
i	interest rate
LFC	low-pressure flash chamber
LPT	low-pressure turbine
m	mass flow rate (kg/s)
M	molecular weight (kg/kmol)
N	system life (yr)
Q	heat transfer rate (kW)
r	relative cost difference (%)
R	gas constant (kJ/kmol.K)
s	specific entropy (kJ/kg.K)
SV	separation vessel
T	temperature (^{o}C)
TA	turbine assembly
TCI	total capital investment
W	electric power (kW)
X	concentration
Y	ratio of exergy destruction ratio (or loss)
Z	investment cost rate of system components (\$/hr)
Greek letters	
γ	maintenance factor
η	efficiency (%)
τ	number of system operating hours (hr)
Superscripts	
ch	chemical
CI	capital investment
dis	dissolution
ph	physical
OM	operation and maintenance
Subscripts	
Abs	absorber
Con	condenser
D	exergy destruction
DW	distilled water
e	outlet
Eva	evaporator
ex	exergy
F	fuel
Gen	generator
i	inlet
k	*k*th component of system
L	exergy losses
o	environment
OPT	optimal
p	product
R	reference
th	thermal
w	work
0	standard state

for power generation, by heating the binary working fluids (Luo et al., 2012; Coskun et al., 2014). Yari (2010) performed an exergetic analysis on various types of power plants that utilize high temperature geothermal sources. The results showed that the highest energy efficiency was obtained for a system that used R123 as the working fluid in the ORC subsystem. Wang et al. (2015) replaced, in a flash-binary geothermal power system, the ORC cycle with a Kalina cycle. Zhao and Wang (2016) investigated thermoeconomically a flash-binary geothermal power system that utilize an ORC subsystem. It was observed that the most economically effective system does not necessarily have the superior thermodynamic performance, and the most thermodynamically effective system is not necessarily the most economic.

Today, various thermal resources and thermal plants emit large quantities of waste heat at low temperature, i.e., 60–100 °C (Horuz and Kurt, 2010). Using this energy can be advantageous for conserving energy resources, and decreasing fuel consumption and environmental pollution. To fulfill the aim of saving energy, absorption heat transformers (AHTs) operating with a small amount of shaft power are utilized to upgrade a fraction of waste heat energy (Mahmoudi et al., 2017a). In double-flash geothermal power systems the reinjected geofluid has a temperature higher than 50 °C. The temperature of this stream can be raised using absorption heat transformers and reused for other applications. Also, desalination is an important technology to securing fresh water supplies at a time when water scarcity around the world coincides with record consumptions of fresh water and many researchers are looking for a technology to help in meeting the demands. Since the output upgraded energy in AHT systems has a temperature of more than 100 °C, it can be used for water desalination purposes. Recently, several studies have been performed on AHT systems combined with water desalination systems and their performances. Parham et al. (2013) examined a modified system with a water desalination system and a single-stage absorption heat transformer. Their combined system could yielded a 0.2435 kg/s mass flow rate of distilled water. Gomri (2010) integrated double and single absorption heat transformers with water desalination to investigate the distilled water production rate. He showed that single absorption heat transformers have higher rates of distilled water than double absorption systems. Sekar and Seravanan (Sekar and Saravanan, 2011) carried out an experimental analysis of an absorption heat transformer coupled with water desalination. The results indicate a maximum production water rate of 4.1 kg/h, for a system with a COP of 0.30–0.38. Yari et al. (2017) proposed a new type of double-stage absorption heat transformer, combining it with water desalination. The authors compared its performance with four other double absorption heat transformers, and showed, for the proposed type of double absorption heat transformer, the maximum gross temperature lift is about 18–27% higher than for the other considered systems. Mahmoudi et al. (2017b) proposed a