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Effects of different operating conditions of Gonen geothermal district heating system on its annual performance

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ABSTRACT

In this paper, the effects of different operating conditions of the Gonen geothermal district heating system (GDHS) on its annual energy and exergy performance are investigated. The system parameters such as temperature, pressure and flow rate are monitored by using fixed and portable measuring instruments over a one-year period. Thus the main differences in the annual system operation are detected. The measurements show that the Gonen GDHS has six different operating cases depending on the outside temperature throughout the year. The energy and exergy analysis of the system is carried out for each case using the actual system parameters at the corresponding reference temperatures, which are 3.86, 7.1, 8.88, 11.83, 15.26 and 20.4 °C. The highest and lowest energy (57.32%, 35.64%) and exergy (55.76%, 41.42%) efficiencies of the overall system are calculated at the reference temperatures of 15.26 °C and 3.86 °C, respectively. Besides, taking the six case-based energy and exergy analyses into account, the annual average energy and exergy efficiencies are determined to be 45.24% and 47.33%, respectively.

1. Introduction

Turkey is among the first seven countries in terms of the abundance of geothermal resources around the world. About 1000 hot and mineralized natural self flowing springs exist in Turkey. The geothermal potential of Turkey is estimated as about 31,500 MWt for direct use and 4500 MWe for power generation [1,2]. District heating in Turkey began in 1987 with Gonen GDHS heating 600 residences. Following the Gonen GDHS, 19 other GDHSs were installed and the calculated thermal capacity, based on the amount of hot water delivered in 2008 and the difference between inlet and outlet temperatures, reached around 395 MWt [3].

Despite more than 20 years of operation in the field, the survey studies carried out for the overall Gonen GDHS reveals that considerable deficiencies still exist during the system operation. The inability of accurate and regular measurement of the system parameters, poorly designed and installed mechanical system and the lack of automatic controlling of the processes are some of these deficiencies in the Gonen GDHS. It is therefore inevitable for the Gonen GDHS to be assisted by the new investments in the short run for achieving the economic operation conditions. However, a comprehensive system analysis and performance evaluation have to be conducted in order to determine the required measures for eliminating the above problems and improve the system efficiency.

Since the exergy analysis was the first used by Badvarsson and Eggers [4] in analyzing a geothermal power plant in 1972, it has proven to be a powerful tool in the thermodynamic analysis of energy systems. Exergy analysis method is employed to detect and quantitatively evaluate the causes of the thermodynamic imperfection of the process under consideration. It can, therefore, indicate the possibilities of thermodynamic improvement of the process under consideration [5]. Thermodynamic indicators of performance based on the second law are commonly accepted as the most natural way to measure the performance of GDHSs [6,7].

The heating load of a GDHS constantly changes throughout the year due to unsteady outside air conditions. This affects the energy production rates, fields of energy use, operating diagram and number of active components of the systems and therefore the GDHSs work in different operating conditions. The location, type and magnitude of the wastes and losses in the systems vary due to these unsteady conditions. These changes inevitably influence the annual energy and exergy performances of the systems.

Most of the studies on the energy and exergy analysis of the GDHSs have been carried out either at a single reference temperature representing a specific winter operating condition in which the systems work at full capacity or at several reference temperatures in a heating season in which the systems work at partial

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Nomenclature

$\dot{E}$	energy rate (kW)
$\dot{E}x$	exergy rate (kW)
$\dot{F}$	exergy rate of the fuel (kW)
h	specific enthalpy (kJ/kg)
$\dot{I}$	irreversibility (exergy destruction) rate (kW)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
$\dot{P}$	exergy rate of the product (kW)
$\dot{Q}$	rate of heat (kW)
R	experimental result
s	specific entropy (kJ/kg K)
$\dot{S}$	entropy rate (kW/K)
$SExI$	specific exergy index (dimensionless)
T	temperature (°C or K)
$\dot{V}$	volumetric flow rate (l/s)
w	total uncertainty
$\dot{W}$	work rate, power (kW)
x	independent variable

Greek symbols

η	energy or first law efficiency (%)
ε	exergy or second law efficiency
ψ	flow exergy (kJ/kg)

Subscripts

cf	calibration facility
dest	destroyed
gen	generation
gf	gas formation
he	heat exchanger
i	successive number of elements
ie	installation effect
in	inlet
k	location
li	linearity
lts	long term stability
out	outlet
pe	pressure effect
pri	primary
r	reinjected geothermal fluid
re	repeatability
sec	secondary
te	temperature effect
Tot	total
w	well-head
wa	waste thermal water
0	reference state

Abbreviations

ECC	energy consumption circuit
EDC	energy distribution circuit
EPC	energy production circuit
G	geothermal well
GDHS	geothermal district heating system
HE	heat exchanger

capacities [8–15]. However, the related studies does not include the effects of the summer or transition operating conditions of the GDHSs in which the space heating is not performed, on the annual energy and exergy performances of the systems. Besides, during a one-year operation period, many GDHSs spend most of their time only providing their users with hot water for different purposes (sanitary water, thermal therapy, process water, etc.) instead of space heating. Ozgener et al. evaluated the energetic and exergetic performance of three GDHSs, namely Balcova, Salihli, and Gonen, by using the system parameters obtained at a reference temperature of 4 °C. The energy efficiencies of 39.6%, 55.6%, 44.5% and the exergy efficiencies of 45.7%, 59.8%, 63% were calculated for the Balcova, Salihli and Gonen GDHSs, respectively [8]. A comprehensive energy and exergy analysis was investigated on the Afyon GDHS by using the system parameters obtained in January 8, 2009 at a reference temperature of 9.2 °C [9]. Ozgener and Ozgener monitored a number of variables of Salihli GDHS in 2007–2008 heating season, for different reference state values, basically from 0 °C to 20 °C for a better coverage and presentation of how the varying reference state temperature affects the performance of the system in term of energy and exergy analysis. As a result, the energy and exergy efficiencies were found to be between 55–67% and 57.23–80% for the 2007–2008 heating season, respectively [10].

As expected, the GDHSs work under different operating conditions throughout the year and therefore the study remains incomplete in case where energy and exergy analysis is carried out only for the winter period of the year. In the current study, it is aimed to investigate the energy and exergy performance of the Gonen GDHS under all circumstances which the system experiences throughout the year. In this extend, the system parameters such as temperature, pressure and flow rate are monitored by using fixed and portable measuring instruments and the main differences in the operating conditions of the system are observed over a one-year period. The number of active geothermal well is used as distinctive criterion in determining the operating conditions of the Gonen GDHS. As a result of this, the Gonen GDHS is proved to work in six different operating cases throughout the year. The energy and exergy analysis of the system is carried out for the each case using the actual system parameters at the corresponding reference temperatures. Besides, taking the six state-based energy and exergy analyses into account, the annual average energy and exergy efficiencies are determined.

2. Material and methods

2.1. Description of the Gonen geothermal district heating system

The Gonen GDHS, installed in Gonen, Balikesir, is the first district heating system of Turkey. It began operation for 600 residences in 1987. As of 2009, almost 300,000 m^2 of indoor space was heated by the system. In the Gonen GDHS, the geothermal energy is used not only for residential heating but also for hotel heating with a closed area of 23,860 m^2. Besides, the system constantly provides its subscribers with hot water, 40 tanneries with process water and the hotels with thermal water and is therefore operative throughout the year.

During the study in 2009, the Gonen GDHS had 17 wells in total ranging in depth from 133 to 800 m. Seven of them were production wells, one was reinjection well while the rest were out of service. The temperature ranges of the production wells varied between 50 and 94 °C while the flow rates varied between 8 and 28 kg/s.