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Comparing advanced exergetic assessments of two geothermal district heating systems for residential buildings

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ABSTRACT

Advanced exergy analysis method has been increasingly utilized in analyzing and assessing the performance of energy-related systems in recent years due to more deeply investigating the exergy destructions. In this study, two various geothermal district heating systems (GDHSs), the Afyon and Bigadiç GDHSs, which have been operated in Turkey, were considered to perform their advanced exergy analyses and assessments. The GDHSs studied were also compared with each other for the first time in terms of advanced exergetic aspects. In the analyses and calculations of the GDHS, the actual operational data obtained from the measurements and technical staff were utilized.

The overall conventional and advanced exergetic efficiency values for the Afyon GDHS are determined to be 27.53% and 34.72% while those for the Bigadiç GDHS are obtained to be 21.03% and 32.52%, respectively. Considering both the interactions among components and the potential for improving components, more effective and efficient improvement priorities were proposed.

1. Introduction

Geothermal energy is considered a cleaner and lower price alternative as far as the ultimate applications in fossil fuels are concerned. It has the lowest energy cost in renewable energy resources. About 4% of Turkey's geothermal energy potential is effectively being utilized despite the huge geothermal energy potential. It can be an important alternative for Turkey's energy requirement while Turkey can supply 12.7% (heat + electricity) of total energy requirement using geothermal energy sources. Geothermal energy can be categorized in two groups, namely electricity production and direct utilization. Direct geothermal energy utilization in Turkey has increased for the last 40 years and exists at the fifth position worldwide [1,2].

A new direction in exergy analysis is called advanced exergy analysis, in which the exergy destruction is split into four subparts, namely endogenous/exogenous and unavoidable/avoidable parts. Various studies on advanced exergy-based analyses of energy systems have been done by many investigators [e.g., 3–10] to improve the accuracy of exergy analysis. In this regard, Morosuk and Tsatsaronis [3] utilized advanced exergetic analysis for better understanding the operation of a three-cascade refrigeration system in liquefaction of natural gas. They investigated improving the thermodynamic efficiency potential of the system components along with the whole system. The interactions among the components and their effect on the exergy destruction within each component were also studied. Tsatsaronis and Morosuk [4] applied the advanced exergy analysis to chemically reacting systems by analyzing a simple gas-turbine system. Petrakopoulou et al. [5] analyzed the combined cycle power plant through both conventional and advanced exergetic analyses. They reported that most of the exergy destruction in the plant components was unavoidable. They also suggested exergy based new improvement strategies for the combined cycle power plant. Morosuk and Tsatsaronis [6] performed an advanced exergetic analysis of a novel system for generating electricity and vaporizing liquefied natural gas. They made some suggestions toward improving the investigated system efficiency. Morosuk and Tsatsaronis [7] evaluated the performance of refrigeration machines with different working fluids using advanced exergetic analysis method. Their study presented the combined application of both concepts to vapor-compression refrigeration machines using different one-component working fluids (R125, R134a, R22 and R717) as well as azeotropic (R500) and zeotropic (R407C) mixtures. Morosuk et al. [8] performed conventional thermodynamic and advanced exergetic analyses of a refrigeration machine using a Voorhees' compression process. In

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Nomenclature

e	specific exergy (kJ/kg K)
$\dot{E}$	exergy rate (kJ/s or kW)
h	enthalpy (kJ/kg K)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
s	entropy (kJ/kg K)
T	temperature (°C or K)
y	exergy destruction ratio (%)

Greek symbol

ε	exergy/exergetic or second law efficiency (%)

Subscripts

ch	chemical
D	destruction
F	fuel
j	stream
k, *r*	components
L	loss
n	number of component
ng	natural gas
P	product
sys	system
tot	total/overall
w	wells
0	reference state

Superscripts

AV	avoidable
EN	endogenous
EX	exogenous
MX	mexogenous
UN	unavoidable

Abbreviations

ECC	energy consumption cycle
EDC	energy distribution cycle
EES	engineering equation solver
EPC	energy production cycle
GDHS	geothermal district heating system
HEX	heat exchanger
LHV	lower heating value
PM	pump
PS	peaking system

their paper, for the first time, in addition to the detailed energetic analysis, for showing the limitations of the energetic analysis in such a complex process, a conventional and an advanced exergetic analysis methods were utilized. As far as studies on advanced exergy-based analyses of GDHSs are concerned, Keçebaş and Hepbasli [9,10] made the conventional and advanced exergoeconomic analyses of GDHSs. The results of their study indicated that the internal design change played a more essential role in determining the cost of each component. The cost rate of unavoidable part within the components of the system was lower than that of the avoidable one.

In this study, advanced exergetic analysis methods are applied to compare two GDHSs, the Bigadic and Afyon GDHSs in Turkey, based on the actual operational data. The above presented aspects provided the main motivation behind performing this contribution, of which objectives are to (i) apply advanced exergy analysis to two GDHSs and evaluate their performance in parts, (ii) compare them with each other, and (iii) discuss the performance and possible improvements in the two systems.

2. Description of the GDHSs studied

2.1. Afyon GDHS

The Afyon GDHS installed in 1994 provides residential heating for buildings through geothermal water while it was initially designed for 10,000 residences with a potential of 48.333 MW_{th}. The average reservoir temperature of wells in this field is 105 °C. A schematic of the Afyon GDHS is illustrated in Fig. 1 [9,11], which includes three main cycles. In the energy production cycle (EPC), geothermal fluid collected from the production wells is sent to the inlet of the mixing pool via a main collector with a total mass flow rate of about 175 kg/s. The fluid at an average temperature of about 95 °C is then pumped through the main pipeline to the Afyon GDHS, located in the center of the Afyonkarahisar province. The geothermal fluid flows through the six heat plate exchangers with a total capacity of about 18.6 MW in the geo-heat mechanical room of the Afyon GDHS and is cooled to about 45–50 °C. Because the maximum discharge mass flow rate of the residential heating (175 kg/s) is beyond the total re-injection mass flow rate (122.2 kg/s), the remaining fluid is released to the nature direct discharge. In the energy distribution cycle (EDC), the hot water is pumped to the six heat exchangers and then the supply (flow) water is sent to the heat exchangers installed under each building in the zones. The mean supply/return water temperatures of the building cycle are 60/45 °C. Through control valves for flow rate and temperature at the main building station, the amount of water needed is adjusted and sent to each housing unit and the heat balance of the system is achieved. However, the analysis did not cover the energy consumption cycle (ECC). The actual operational data on temperature, pressure and flow rate of the system have been hourly recorded since 2006 [9,11,12].

2.2. Bigadic GDHS

The well head temperature of the Bigadic geothermal field located 38 km south of the city of Balıkesir, Turkey is 96 °C. Geothermal mass flow rate decreased from 70 kg/s to 25 kg/s from 2006 to 2011 years. The Bigadic GDHS contains three main cycles, as indicated in Fig. 2 [13,14]. In the first cycle, the geothermal fluid is pumped to the mechanical room after passing through the mud and gas separator unit. There is an 18 km long pipeline between the geothermal source and the mechanical room. Pipelines coming from geothermal source to the heating center is designed and constructed for a mass flow rate of 100 kg/s. When the mass flow rate decreases to 25 kg/s, the residence time of the water in the pipe is prolonged. So, the heat losses increase. In the second cycle, the geothermal fluid is cooled to approximately 40.6 °C in the heat exchangers constructed in the mechanical room. After the heat transfer taking place in the heat exchangers, the geothermal fluid is sent to pipelines. In the third cycle, clean hot water is pumped to the heat exchangers located under each building. The system is designed to have one or two heat exchangers for each building. One heat exchanger is for heating, and the other is for hot water requirements. The system has no reinjection and the geothermal water is sent to the river after the utilization. The system is assisted with an additional heating center [13,14].

3. Methodology used

The initial results of the conventional exergetic analysis of each GDHS have been presented in [11–14]. The results presented here