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An economic comparison and evaluation of two geothermal district heating systems for advanced exergoeconomic analysis

Pınar Keçebaş [a], Harun Gökgedik [a,b], Mehmet Ali Alkan [c], Ali Keçebaş [d,*]

[a] Department of Energy, Graduate School of Natural and Applied Science, Muğla Sıtkı Koçman University, 48000 Muğla, Turkey
[b] Department of Energy Systems Engineering, Graduate School of Natural and Applied Science, Süleyman Demirel University, 32260 Isparta, Turkey
[c] Department of Electricity and Energy, Ula Ali Koçman Vocational High School, Muğla Sıtkı Koçman University, 48640 Ula, Muğla, Turkey
[d] Department of Energy Systems Engineering, Technology Faculty, Muğla Sıtkı Koçman University, 48000 Muğla, Turkey

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ABSTRACT

This paper refers to an economic comparison and evaluation of two geothermal district heating systems (GDHSs) under same reference state condition and mechanic/economic parameters by using an advanced exergoeconomic analysis. In this analysis, costs of investment and exergy destruction of each component for the thermal systems such as the Afyon and Sarayköy GDHSs were split into endogenous/exogenous and unavoidable/avoidable parts, and were also compared with each other for the first time. The results obtained show that the advanced exergoeconomic analysis makes the information more accurate and useful, and supplies additional information that cannot be provided by the conversional analysis. Furthermore, the Afyon GDHS can be made more cost effectiveness, removing the system components' irreversibilities, technical-economic limitations, and poorly chosen manufacturing methods, according to the Sarayköy GDHS. The majority of the components in the Sarayköy GDHS are to operate more economically than those in the Afyon GDHS. As a result, the usefulness of this method was clearly demonstrated comparing both the systems.

1. Introduction

Two important problems faced by the world are environmental pollution and the increasing energy demand. Therefore, energy resources must be used more effectively. It is irrefutable that an efficient thermal system produces less green-house gases and uses energy more effectively. The effectiveness of an energy conversion system can be evaluated by conventional exergy based analyses (thermal, economic and environmental). However, these analyses do not provide enough information about the relations between the components and they are inadequate in determining the real improvement potentials. Briefly, a thermodynamic, economic and environmental analysis methods, which is called the advanced exergy based analyses, was developed to resolve the deficiencies in the conventional exergy based analyses [1]. For example, the exergy destruction, the exergy costs, the investment and the environmental effect for any component can be considered to be a result of the component itself or other components. The advanced exergy based analysis simultaneously provides everyone in the formation about the improvement limits of the considered component or the system, which resulted from technical, economic and ecological constraints.

In this study, it is focused the advanced exergy based analysis methods especially economic. Advanced exergoeconomic analysis is a new method and it uses the results of the corresponding conventional exergy based analyses, but advance the examination process by introducing new calculation steps to reveal component interactions and potential for improvement [2–4]. In the literature, its applications to various energy conversion systems are relatively low in numbers [1,3,5–13]. Tsatsaronis and Moung-Ho [5] were the first to develop the concepts of avoidable and unavoidable exergy destructions, which are used to determine the potential of improving the thermodynamic performance and the cost effectiveness of a system. Cziesla et al. [3] investigated all components of an externally fired combined power plant according to both avoidable and unavoidable exergy destructions; the associated costs were defined, and the results of their study were discussed. Tsatsaronis [6] discussed the weaknesses of the conventional exergy based analyses in developing improvement strategies and presented advanced exergy, advanced exergoeconomic and exergoenvironmental analyses as the solutions to these weaknesses. In Refs.

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* Corresponding author. Tel.: +90 252 2115471; fax: +90 252 2113150.
E-mail addresses: alikecebas@mu.edu.tr, alikecebas@gmail.com (A. Keçebaş).

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Nomenclature

c	cost per unit of exergy ($/h)
$\dot{C}$	cost rate associated with exergy ($/h)
$\dot{E}$	exergy rate (kJ/s or kW)
f	exergoeconomic factor (%)
MX	mexogenous
P	pressure (kPa)
PEC	purchased-equipment cost ($)
T	temperature (°C or K)
$\dot{Z}$	cost rate associated with capital investment ($/h)

Greek symbols

Δ	difference
η	energy/energetic or first law efficiency (%)

Subscripts

D	destruction
F	fuel
is	isentropic
k, r	components
L	loss
mech	mechanical
P	product
Q	heat transfer
tot	total/overall
W	power
0	reference state

Superscripts

AV	avoidable
CI	capital investment
EN	endogenous
EX	exogenous
MX	mexogenous
OM	operating and maintenance
UN	unavoidable

Abbreviations

ECC	energy consumption cycle
EDC	energy distribution cycle
EPC	energy production cycle
GDHS	geothermal district heating system
HEX	heat exchanger
PM	pump
SPECO	specific exergy costing

[7,8], the advanced exergoeconomic analysis was applied in a combined heating and power system and an oxy-fuel power plant with CO_2 capture, and the methodology that was used to perform the advanced exergoeconomic analysis was explained in a detail. Wei et al. [9] presented an exergy analysis and an exergoeconomic evaluation based on the concepts of avoidable/unavoidable exergy destructions and investment costs to identify the potential energy savings in distillation processes. Petrakopoulou et al. [10] presented the first application of an advanced exergoeconomic analysis to a complex combined-cycle power plant with CO_2 capture. Manesh et al. [11] introduced a systematic procedure for optimal design and evaluation of cogeneration systems based on the accurate cogeneration targeting model and the development of the *R*-curve concept through advanced exergetic, exergoeconomic and exergoenvironmental analyses. Açıkkalp et al. [1] evaluated thermo-economically the electricity-generating facility that operates with evaluation natural gas in the Eskisehir Industry Estate Zone/Turkey for advanced exergoeconomic analysis.

In addition to above-mentioned studies, according to the current knowledge of the authors, there are only two studies, which assessed a geothermal district heating system (GDHS) through advanced exergoeconomic analysis method [12,13]. Keçebaş and Hepbasli [12] assessed and compared the conventional and advanced exergoeconomic analyses to identify the direction and potential for energy savings of a GDHS in future conditions/projections. Tan and Keçebaş [13] analyzed with exergy-based methods to evaluate performances of each component and identify possible solutions to improve overall system performance from the initial system design of a GDHS. The above presented aspects provide the prima motivation behind performing this contribution with the objectives of (i) applying advanced exergoeconomic analysis to two GDHSs under same reference state condition and mechanic/economic parameters based on actual operational data, (ii) comparing and evaluating their economic performances in the splitting processes, (iii) comparing results obtained by the conventional and advanced exergoeconomic analysis with each other, and (iv) discussing the performance and possible improvements in the GDHSs.

2. Description of the compared systems

To provide residential heating for buildings through geothermal water, the Afyon and Sarayköy GDHSs were installed respectively in the cities of Afyonkarahisar and Denizli of Turkey in 1994 and 2002. While the Afyon GDHS was initially designed for 10,000 residences with a potential of 48.3 MW_t, there are only 4613 residences nowadays that have been heated. For the Sarayköy GDHS, there are only 2350 residences of 5000 residences with a potential of 27.2 MW_t. Their heat sources originate the geothermal fluid with 225 kg/s and 105 °C from the Ömer–Gecek geothermal field, and the waste geothermal fluid of the Zorlu Geothermal Energy Electricity Generation Inc. with 56 kg/s and 125 °C for the Afyon and Sarayköy GDHSs, respectively. In this study, the Afyon and Sarayköy GDHSs were investigated, and their schematics, which mainly consists of three cycles, namely, (i) the energy production circuit (EPC), (ii) the energy distribution circuit (EDC) and (iii) the energy consumption circuit (ECC), is illustrated in Figs. 1 and 2, respectively. In the energy production circuit, the waste geothermal fluid is sent at a rate of 200 ton/h to the Sarayköy GDHS at approximately 2.2 bar pressure and temperature of 125 °C while the geothermal fluid at an average flow rate, temperature and pressure of 630 ton/h, 95 °C and 8 bar (for 14,650 m length) is pumped to the Afyon GDHS. Next, all of the waste geothermal fluid (200 ton/h) for the Sarayköy GDHS is released via natural direct discharge. For the Afyon GHDS, because the maximum discharge mass flow rate of the residential heating (630 ton/h) is beyond the total re-injection mass flow rate (440 ton/h), the remaining fluid is released to the nature direct discharge. For the supply/return water temperatures of the building (energy consumption) cycle, The Sarayköy GDHS has about temperatures of 60/45 °C while these are 70/50 °C for the Afyon GDHS. The actual operational data regarding the temperature, pressure and flow rate of the systems were recorded on January 20, 2013 and February 16, 2012 by the technical staffs based on the state numbers specified in Figs. 1 and 2 for the Afyon and Sarayköy GDHSs, respectively. In each system, the pressure and temperature data on the fluids (including the geothermal fluid and the hot