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Conventional and advanced exergoeconomic analyses of geothermal district heating systems

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ABSTRACT

The present study deals with analyzing, assessing and comparing conventional and advanced exergoeconomic analyses to identify the direction and potential for energy savings of a geothermal district heating system in future conditions/projections. As a real case study, the Afyon geothermal district heating system in Afyonkarahisar, Turkey, is considered while its actual operational thermal data on 8 February 2011 are utilized in the analysis, which is based on the specific exergy costing method. In this study for the first time, based on the concepts of avoidable/unavoidable and endogenous/exogenous parts, cost rates associated with both exergy destruction and capital investment of the geothermal district heating system are determined first, and the obtained results are then evaluated. The results indicate that the internal design changes play a more essential role in determining the cost of each component. The cost rate of unavoidable part within the components of the system is lower than that of the avoidable one. For the overall system, the value for the conventional exergoeconomic factor is determined to be 5.53% while that for the modified one is calculated to be 9.49%. As a result, the advanced exergoeconomic analysis makes more sense given the additional information in splitting process of the components.

1. Introduction

Geothermal district heating has recently been given increasing attention in many countries (France, Iceland, USA, China, Japan, Turkey, etc.) and a number of successful geothermal district heating projects have been realized and reported [1]. Turkey is also one of the top five countries for geothermal direct applications [2] due to its large number of geothermal district heating systems (GDHSs). The share of its potential used is, however, relatively very low. In Turkey, GDHS applications were started with large scale, city based GDHSs in 1987 [3]. Since then, many GDHSs have been installed.

Exergy is considered to be a way to sustainability while exergy analysis has been recently widely used as a very useful tool for performance assessment of energy-related systems as well as sustainable buildings [4]. Exergy analysis helps identify the inefficiencies caused by the irreversibilities within the system being. Therefore, the location, the magnitude and the sources of inefficiencies and costs may be determined, through exergy based methods. Exergoeconomic (or thermoeconomic) analysis also combines both exergy and economic analyses. It is based on the exergy costing principle, which assigns monetary values to energy streams and to the thermodynamic inefficiencies within the system [5]. It also provides designers or operators of energy conversion systems with essential information on designing a cost-effective system [6].

Advanced exergy analysis has been recently seen as a new direction in exergy analysis and performance assessment. It splits the exergy destruction into endogenous/exogenous and unavoidable/avoidable parts and can help in improving the accuracy of exergy analysis. So, it enables a better understanding of the thermodynamic inefficiencies in any system considered [7].

Using an advanced exergoeconomic analysis, the exergy destruction cost associated with a component may be calculated and compared with the investment cost of the same component. The main aim behind this is to decide about the design changes that might improve its cost effectiveness [6]. In this regard, the exergy destruction and the investment costs in each component are split into avoidable/unavoidable and endogenous/exogenous parts.

In 1892 the first GDHS began operations in Boise, Idaho, USA. Since then, a number of GDHSs installations have been realized worldwide [8]. The performance of these systems has been mostly energetically assessed. However, especially over almost last nine years, these systems have been started evaluating in terms of conventional exergetic and exergoeconomic aspects, focusing on the Turkish GDHSs. Some studies [e.g., 8,9] on conventional

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.

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Nomenclature

c	cost per unit of exergy ($/h)
$\dot{C}$	cost rate associated with exergy ($/h)
$\dot{E}x$	exergy rate (kJ/s or kW)
f	exergoeconomic factor (%)
P	pressure (kPa)
r	relative cost difference (%)
T	temperature (°C or K)
$\dot{Z}$	cost rate associated with capital investment ($/h)

Greek symbols

Δ	difference
ε	exergy/exergetic or second law efficiency (%)
η	energy/energetic or first law efficiency (%)

Subscripts

D	destruction
F	fuel
is	isentropic
k, r	components
L	loss
$mech$	mechanical
n	number of component
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

exergoeconomic analysis and performance assessment of GDHSs have been made, as comprehensively reviewed by Hepbasli [8] elsewhere.

In the open literature, only one study, which has been recently performed by the authors [10], on advanced exergetic analysis of a GDHS exists while no studies on advanced exergoeconomic analysis of GDHSs have appeared to the best of the authors' knowledge. In this context, the main objectives of this contribution are to (i) undertake a further study to model and analyze the advanced exergoeconomic aspects of GDHSs, (ii) apply the model to the Afyon GDSH in Turkey, which was selected as an application place, and (iii) assess its performance through some exergoeconomic parameters considered.

2. Description of the geothermal district heating system studied

The GDHS considered as an application place of the analysis in this study, namely the Afyon GDHS, was installed in 1994 to provide residential heating for buildings through geothermal water. It was initially designed for 10,000 residences with a potential of 48.333 MW_t. Its heat source originates from the Ömer-Gecek geothermal field, 15 km north-west of the city of Afyonkarahisar. There are four artesian production wells (called AF11, AF16, AF18, and AF21). The wells in this field have an average reservoir

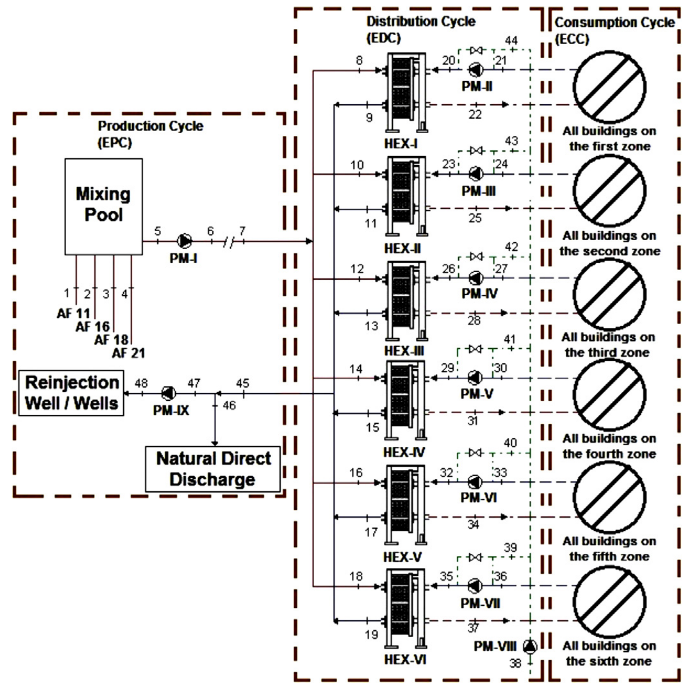

Fig. 1. Schematic diagram of the Afyon GDHS investigated (modified from Refs. [11,12]).

temperature of 105 °C. The data on the wells, including depth, production type, temperature and discharge rate, can be obtained from Refs. [11,12] while the system description is summarized below.

Fig. 1 schematically shows the Afyon GDHS. The system has three main cycles, namely (i) the energy production cycle (EPC), (ii) the energy distribution cycle (EDC), and (iii) the energy consumption cycle (ECC). For the EPC in this GDHS, 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 approximately 95 °C is then pumped through the main pipeline to the Afyon GDHS, located in the center of the Afyonkarahisar province. The geothermal fluid is sent to the six heat plate exchangers with a total capacity of about 18.6 MW (16 million kcal/h) 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. For the 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 all the buildings 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 ECC of the Afyon GDHS was not considered in the analysis.

The technical staff of the GDHS have hourly collected and recorded the actual operational data on temperature, pressure and flow rate of the system since 2006 based on the state numbers specified in Fig. 1. Bourdon-tube pressure gauges and fluid-expansion thermometers have been utilized in the measurements of the pressure and temperature data on the fluids (including hot water and geothermal fluid), respectively. An ultrasonic flow meter has also been used to measure the volumetric flow rates of fluids.