Energy and Buildings 127 (2016) 794–804

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Energy and exergy based evaluation of the renovated Afyon geothermal district heating system

Hilmi Yazici

Automotive Engineering Department, Technology Faculty, Pamukkale University, 20020 Denizli, Turkey

ARTICLE INFO

Article history:
Received 11 April 2016
Received in revised form 9 June 2016
Accepted 10 June 2016
Available online 14 June 2016

Keywords:
Geothermal energy
District heating system
Exergy analysis
Energy analysis

ABSTRACT

In this study, the exergy and energy analyses of the Renovated Afyon Geothermal Heating System (NAF-JET), which was completely renovated in the Afyon province of Turkey between the years 2011–2013, were conducted. The exergy destruction in the overall geothermal district heating system (GDHS) was quantified and illustrated using exergy flow diagrams. Both energy and exergy flow diagrams were presented for comparison purposes. The analyses revealed that the exergy destruction in the system took place particularly due to the exergy of the thermal water (geothermal fluid) re-injected, the heat exchanger losses, the losses of all pumps and pipeline loses, accounting for 15.94%, 12.44%, 5.52% and 5.52% of the total exergy input to the system. Both energy and exergy efficiencies of the overall system were investigated, and they were found to be 46.17% and 60.63%, respectively.

1. Introduction

The world's need for energy increases every passing day. To meet this need, different energy sources are investigated, or the ways for using the existing energy sources more efficiently are preferred. As it is used in many areas of life, energy is also used for building heating. Fossil fuels used to be consumed for building heating. Particularly after the second half of the 20th century, geothermal energy also started to be used for building heating.

Recently, there has been an increasing interest in geothermal energy applications due to its minimum negative effects, low operating expenses, decentralized production advantages and simple technology. The use of geothermal energy can be categorised in two groups as electricity production and direct utilisation [1]. In direct utilisation, high, medium and low temperature geothermal sources can be used. Heating can also be obtained from low-temperature geothermal energy sources by using geothermal heat pumps.

Conventional electric power production can be realized by using fluid temperatures above 150 °C, but considerably lower temperatures can be used for power generation with the application of binary systems. Ideal inlet temperatures into houses for space heating using radiators is about 80 °C; however, by using floor heating radiators or applying heat pumps or auxiliary boilers, thermal waters at temperatures only a few degrees above the ambient temperature can be used beneficially [2].

In power plants, the power output is the electric energy, whereas it is the heat energy consumed in houses in geothermal heating systems. Every power output is a different form of energy. Calculating how much of the energy that enters the system is turned into utilized energy is quite important in terms of system sizing and investment costs. In electric power plants, heating or cooling systems, as calculating thermal efficiency and COP is important, calculating exergy efficiency is also of significance. Therefore, the exergy efficiency that is an indicator of how much of the energy that enters a system is used (i.e. utilized proportion of energy) should be calculated.

At the end of 2014, the direct utilisation is equal to 70,329 MW_t, and the thermal energy used is 587,786 TJ/yr (163,287 GWh/yr). The distribution of thermal energy used by category is approximately 55.3% for ground-source heat pumps, 20.3% for bathing and swimming (including balneology), 15.0% for space heating (of which 89% is for district heating), 4.5% for greenhouses and open ground heating, 2.0% for aquaculture pond and raceway heating, 1.8% for industrial process heating, 0.4% for snow melting and cooling, 0.4% for agricultural drying, and 0.3% for other uses. Turkey is among the first five leading countries after China, USA, Sweden and Germany in its applications of directly using geothermal energy, accounting for 65.8% of the world capacity (MW_t) [3].

In Turkey, the installed capacity and annual energy usage for the various direct-use applications are: 420 MW_t and 4635 TJ/yr for individual space heating, 805 MW_t and 8885 TJ/yr for district heating, 612 MW_t and 11,580 TJ/yr for greenhouse heating, 1.5 MW_t and 50 TJ/yr for agricultural drying, 1005 MW_t and 19,106 TJ/yr for

E-mail address: hyazici@pau.edu.tr

http://dx.doi.org/10.1016/j.enbuild.2016.06.036
0378-7788/

Nomenclature

E	Energy (kJ)
Ex	Exergy (kJ)
$\dot{E}$	Energy rate (kW)
$\dot{E}x$	Exergy rate (kW)
$\dot{F}$	Exergy rate of the fuel (kW)
f	Exergetic factor (%)
h	Specific enthalpy (kJ/kg)
$\dot{I}$	Irreversibility (exergy destruction) rate (kW)
IP	Improvement potential rate (kW)
$\dot{m}$	Mass flow rate (kg/s)
$\dot{P}$	Exergy rate of the product (kW)
P	Pressure (kPa)
$\dot{Q}$	Rate of heat (kW)
s	Specific entropy (kJ/kg K)
$\dot{S}$	Entropy rate (kW/K)
SExI	Specific exergy index (dimensionless)
$\dot{W}$	Work rate, power (kW)
T	Temperature (°C or K)
yr	Year

Greek symbols

η	Energy or first law efficiency (%)
ε	Exergy or exergetic or second law efficiency
ψ	Flow exergy (kJ/kg)
ξ	Productivity lack (%)
χ	Relative irreversibility (%)

Subscripts

d	Natural direct discharge
r	Reinjected geothermal fluid
w	Wellhead
dest	Destroyed
gen	Generation
he	Heat exchanger
i	Successive number of elements
in	Inlet
out	Outlet
0	Reference state
k	Location
t	Thermal
Tot	Total

bathing and swimming, and 42.8 MW_t and 960 TJ/yr for geothermal heat pumps. The total for the country is then 2886.3 MW_t of installed capacity and 45,126 TJ/yr of annual energy usage [4].

Various studies that focus on geothermal systems can be categorised into six groups as: energy and exergy analysis of geothermal power plants [5–10], evaluation of geothermal fields using exergy analysis [11,12] classification of geothermal resources by exergy [13,14], energy and exergy analysis geothermal district heating systems (GDHSs) [15–25], and exergoeconomic analysis of GDHSs [18,26–29].

Aslan et al. investigated the effects of different operating conditions of Gonen geothermal district heating system on its annual performance. The energy and exergy analysis of the system was 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 were 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 were determined to be 45.24% and 47.33%, respectively [29].

Yamankaradeniz carried out thermodynamic performance assessment of a geothermal district heating system (GDHS) using advanced exergetic analysis to identify the interactions among system components and the potential for improvement. This analysis and new exergetic parameters were applied to the Bursa GDHS in Turkey. The results showed that the advanced exergetic analysis was a more meaningful and effective tool than the conventional one for the system performance evaluation. The exergetic efficiencies for the conventional and advanced ones were 25.24% and 26.34%, respectively [30].

Kalinci et al. studied the determination of optimum pipe diameters based on economic analysis and the performance analysis of geothermal district heating systems along with pipelines using energy and exergy analysis methods in the Dikili district of Izmir province. The exergy destruction in the overall system was quantified and illustrated using exergy flow diagrams. Both energy and exergy flow diagrams were presented for comparison purposes. They observed through the analysis that the exergy destructions in the system particularly took place due to the exergy of the thermal water (geothermal fluid) re-injected, the heat exchanger losses, and all pumps losses, accounting for 38.77%, 10.34%, 0.76% of the total exergy input to the system. Exergy losses were also found to be 201.12817 kW and 1.94% of the total exergy input to the all system for the distribution network. For the system performance analysis and improvement, both energy and exergy efficiencies of the overall system were investigated, and were found to be 40.21% and 50.12%, respectively [31].

In this study, the exergy and energy analyses were conducted for the new Afyon geothermal heating system, which is located in the Afyon province of Turkey, and was completely renovated and added additional heating spaces in 2013. The data used in the calculated were obtained on January 15, 2014.

2. System description

The Afyon province is located in the west of the central part of Turkey and the interior areas of the Aegean Region. The location of the Afyon province in Turkey is represented in Fig. 1. Its altitude is 1034 m. It has a steppe climate in which winters are cold and snowy, and summers are hot and dry. In the city centre, fossil fuels and geothermal water are used for house heating.

On 14.02.1994, the Afyon Geothermal Tourism and Trade Co (AFJET) were founded to heat the houses in the city centre with geothermal water. The geothermal water supply located in the Omer-Gecek region in the north-western part of the city 13 km away were only used for bathing until 1994. After that year, the geothermal water in this area started to be used for house heating, hotel heating and heating greenhouses. In 1994, there were 7 wells belonging to AFJET in this region. Five of these were used for production, and two for observation. Until 2006, the geothermal water that is used in house heating was drained into the river Akarcay. In 2006, one of the production wells started to be used as a re-injection well. However, some of the geothermal water was still drained into the river. As of 2011, the whole geothermal water has been re-injected.

The AFJET went through a serious structuring and system renovation between the years 2011–2013. Within this time, the pipelines in the city centre and the main transmission line were renewed. Before 2011, there were only the Karahisar heating centre, and 4500 houses could be heated with geothermal water. As of 2013, the number of heated houses has gone up to 11,000 with the Dervispasa and Uydukent heating centres founded. Besides, an automation system was founded to be able to monitor the whole