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New energy and exergy parameters for geothermal district heating systems

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ABSTRACT

This paper introduces four new parameters, namely energetic renewability ratio, exergetic renewability ratio, energetic reinjection ratio, and exergetic reinjection ratio for geothermal district energy systems. These parameters are applied to Edremit Geothermal District Heating System (GDHS) in Balikesir, Turkey for daily, monthly and yearly assessments and their variations are studied. In addition, the actual data are regressed to obtain some applied correlations for practical use. Some results follow: (i) Both energetic and exergetic renewability ratios decrease with decreasing temperature in heating season and increasing temperature in the summer. (ii) Both energetic and exergetic reinjection ratios increase with decreasing temperature for heating season and increase with increasing temperature for summer season.

1. Introduction

District heating is one of the most common and widespread direct uses of geothermal resources, and such systems are employed to provide space heating and/or cooling to multiple consumers from a single well or multiple wells/fields. The development of geothermal energy, particularly by the Icelanders, has been one of the fastest growing segments of the geothermal space heating industry and now accounts for over 75% of all space heating provided from geothermal resources worldwide [1]. Recently, geothermal district heating has been successfully implemented in many countries, such as USA, Canada, Italy, Iceland, and more recently Japan, New Zealand, China, and Turkey [2,3]. Turkey has also installed large geothermal district heating systems. Turkey's share of geothermal energy use worldwide is about 12.1% (e.g., [4,5]).

Although there have been many investigations on energy analysis, exergy analysis, sources evaluation and classification, performance assessment, and exergoeconomic analysis of various types of geothermal energy systems and applications, there have been only a few studies on some general parameters, namely specific exergy index, fuel depletion ratio, relative irreversibility, productivity lack, and exergetic factor as introduced [6–9] and applied to geothermal district heating systems by several researchers (e.g., [10,12,15–18]). Van Gool [7] has proposed the parameter of exergetic improvement potential as the maximum improvement in exergy efficiency for a process or system. Lee [8] has proposed the parameter of specific exergy index for some degree of classification and evaluation of geothermal resources using their exergy. Fuel depletion ratio, relative irreversibility, productivity lack, and exergetic factor are defined by Ref. [9] for thermodynamic analysis of some systems.

In this study, we aim to develop four new, applied parameters, namely energetic renewability ratio, exergetic renewability ratio, energetic reinjection ratio, and exergetic reinjection ratio for geothermal district energy systems and to validate these parameters using actual thermal data (in terms of temperatures, pressures, and flow rates) as taken from the Edremit Geothermal District Heating System (GDHS) in Balikesir, Turkey. It is also aimed to study how these parameters change daily, monthly and yearly and how these are used to assess geothermal district heating systems.

2. System description

The Edremit geothermal field is located 87 km west of the city of Balikesir which is in the northwest Anatolia. There is a 3–4 km distance between geothermal source and the center of the Edremit. As of November 2007, there were seven wells in geothermal field, with depths ranging from 195 to 496 m. Information for the wells opened is shown in Table 1. Three wells (ED-1, ED-3 and EDJ-3) are currently in use for production. One well (ED-2) is closed because of its insufficient mass flow rate. Other three (EDJ-4, ED-5, EDJ-7) wells have a pump but not yet connected to system. Wellhead

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Nomenclature

$\dot{E}$	energy rate (kW)
$\dot{E}x$	exergy rate (kW)
$Rein_E$	energetic reinjection (-)
$Rein_{Ex}$	exergetic reinjection (-)
Ren_E	energetic renewability (-)
Ren_{Ex}	exergetic renewability (-)
h	specific enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
s	specific entropy (kJ/kgK)
T	temperature (°C or K)
$\dot{W}$	work rate (or power) (kW)
$\dot{I}$	irreversibility (exergy destruction) rate (kW)
$\dot{P}$	exergy rate of the product (kW)
$\dot{F}$	exergy rate of the fuel (kW)
f	exergetic factor (%)
Greek letters	
ψ	specific exergy (kJ/kg)
η	energy (first law) efficiency (%)
ε	exergy (second law) efficiency (%)
δ	fuel depletion rate (%)
ξ	productivity lack (%)
χ	relative irreversibility (%)
Subscripts	
nd	natural direct discharge
usf	useful
gw	geothermal water
sys	system
in	inlet
out	outlet
e	energy
ex	exergy
HE	heat exchanger
dest	destroyed
pipe	pipe line
gw	geothermal water
0	reference (dead) stead
i	successive number of elements

production temperature is 60 °C. Mass flow rates of operating wells chance from 18 to 86 kg/s. Potential of the Edremit GDHS is 9.815 MWt. Edremit GDHS' wells extend over of nearly 0.3 km^2. As of November 2007, Edremit GDHS was reached 1648 dwelling equivalence. The average area and height of a common dwelling are about 100 m^2 and 2.8 m, respectively, corresponding to a residence volume of 280 m^3. The total heat load for such a dwelling is described as dwelling equivalence, and the equivalent dwelling values for the Edremit GDHS is 8.37 kW.

Generally, heating systems become operational when the outdoor temperature falls below 15 °C. On this temperature basis, according to average temperature, there are 191 "colder" (or heat-requiring) days between October 23 and April 30 annually in the Edremit area. In summer or warmer season, during an average of 174 days, only domestic hot water is supplied from Edremit GDHS. In designated period, outdoor design temperature, while determining the heat demand of a dwelling, had been chosen to be −3 °C by project engineers. However the lowest outdoor temperature is about 4.9 °C when considering the average outdoor temperature. Energy is generated from geothermal energy when the outdoor temperature is over the 5 °C. Under 5 °C, the peaking system, which uses the fuel-oil as a fuel, is activated.

Table 1
Explanation of the wells in Edremit geothermal field.

Name	Total depth (m)	Wellhead temperature (°C)	Flow rate (kg/s)	Type/condition
ED-1	195.60	60.00	75	Production/ operating
ED-2	496.50	55.00	2	Closed
ED-3	495.00	59.00	18	Production/ operating
EDJ-3	266.00	60.00	86	Production/ operating
EDJ-4	296.00	49.00	86	Production/out of service
EDJ-5	216.00	58.70	45	Production/out of service
EDJ-7	246.00	58.30	30	Production/out of service

The Edremit GDHS was designed for three stages with the total capacity ultimately corresponding to 7500 dwelling equivalences. In the first stage, heat demand was compensated to 1648 dwelling equivalence. In the second stage, 5000 and in the last stage, 7500 dwelling equivalences will be constructed. In Fig. 1, a schematic diagram of the system is shown. On January 20, 2008, Edremit GDHS supplied the heat requirement of one religious facility, one dormitory, one college, two hospitals and 1345 residences. The essential components of the Edremit GDHS are pumps and heat exchangers as constructed under each building, as well as one under the peaking station. The peaking station is kept for emergency heat requirements, in case the current systems cannot meet the requirements due to extremely low outdoor temperatures and somehow high demand. It is also reserved for system breakdown or natural disaster. The system is designed to have at least one heat exchanger for each building. So now, each building has a heat exchanger to supply its heat requirement. There are 62 buildings, covering 1648 equivalent dwellings in the system. In calculations, it is very difficult to take a fixed value for each heat exchanger. That's why a group of 62 heat exchangers are represented by "HE" in Fig. 1 as a single heat exchanger. Same plate-type heat exchangers are used throughout the system. Inlet and outlet heat exchanger liquid temperatures are measured for both working fluids, namely circulating network water for heating and geothermal fluid. The temperature readings were taken from the farthest building as considered a critical point. It was observed that the difference between critical point and geothermal field is not much, so the effect of elevation is considered negligible in the calculations. The geothermal fluid collected from three production wells, at an average wellhead temperature of 60 °C, is pumped to heat exchangers under the buildings after passing through a peaking station. It was measured that geothermal fluid enters the heat exchangers at an average temperature of 58–59 °C and hence, heat is transferred to the circulating network water for use. After this, geothermal fluid is discharged to the Edremit river at 40–42 °C. No pump is needed for the main distribution pipelines or discharge sections. The pressure supplied from the well pumps is enough for circulation.