Monitoring of Thermoeconomic Analysis of Salihli Geothermal District Heating System (SGDHS)

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Abstract: - The paper describes briefly thermoeconomic analysis of Salihli Geothermal District Heating System (SGDHS) in Turkey. The case study covers the actual system data taken from the SGDHS, Turkey. General thermoeconomic analysis of the SGDHS is introduced. Then this analysis applied to SGDHS using actual thermodynamic data for its performance evaluations in terms of thermoeconomic parameter is presented.

Key-Words: - Energy, exergy, geothermal energy, renewable energy, thermoeconomic

1 Introduction

Space heating with geothermal energy is one of the most common and widespread direct uses of geothermal resources. Space heating is also one of the oldest direct uses of geothermal energy. District heating, and in some cases district cooling, networks are designed to provide space heating and/or cooling to multiple consumers from a single well or from multiple wells or fields. The development of geothermal district heating, led 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 world wide [1]. The main uses of geothermal energy cover a wide range of applications, such as space heating and domestic hot water supply, greenhouse heating, swimming and balneology, industrial processes, heat pumps, and electricity generation. Based upon the current status, the majority of geothermal applications in Turkey have been realized in district heating systems [2].

The total installed capacity, reported at the end of 2004, for the world’s geothermal direct utilization is 27,825 MW, almost a two-fold increase over the 2000 data, growing at a compound rate of 12.9% annually. The total annual energy use is 261,418 TJ (72,622 GWh), almost a 40% increase over 2000, growing at a compound rate of 6.5% annually. Compared to ten years ago the capacity increased 12.4%/yr and the use 8.8%/yr. The countries with the largest installed capacity and annual energy use were the USA, Sweden, China, Iceland, and Turkey, accounting for about 66% of the installed capacity and 60% of the annual energy use [2].

More recently, [3-11] have conducted an exergy and thermoeconomic analysis of geothermal district heating systems in Turkey, and determinate their performance and system parameters. After successful geothermal heating applications were done in SGDHS, home owners (consumers) preferred the usage of geothermal heating systems more than conventional heating systems in their residents. As a result, maximum heated residence equivalence of the system went up to from 2470 to 5400, in 2006/2007 heating season, and new production and re-injection wells drilled, new heat exchangers, and pumps installed in the geothermal field. In past, SGDHS did not have geothermal re-injection well, yet it has six re-injection wells in 2006/2007 and 2007/2008 heating seasons. Therefore, the new thermoeconomic parameter is developed by the authors on the older model for the more realistic thermoeconomic performance evaluation of the system in this study.

In this context, thermoeconomic analysis of Salihli geothermal district heating system (GDHS) installed in Turkey is investigated.
2 System Description

The Salihli geothermal field is about 7 km from the town Salihli (about 55 km far from the city Manisa, located in the western part of Turkey). It has a maximal yield of 0.175 m$^3$/s at an average reservoir temperature of 86°C. Salihli GDHS was initially designed for a capacity to cover 20,000 residences equivalence. Of these, 5470 residences equivalence are heated by geothermal energy as of December 2006. The outdoor and indoor design temperatures for the system are 4°C and 22°C, respectively. Modeled system of main cycles where hospitals, greenhouses, and official buildings heated by geothermal energy were also included. At the beginning of 2007, there were 14 wells ranging in depth from 40 to 513 m in the Salihli GDHS. Of these, 6 wells were in operation at the date studied. Seven wells (designated as K2, K5, K11, K12, K15, K18, and K19) are production, greenhouse and balneology wells. Seven wells (designated as K1, K3, K4, K7, K9, K16 and K17) in the system are reinjection wells. The primary thermal water is reinjected into the well(s) and discharged via natural direct discharge after extracting its enthalpy, while the secondary fluid (i.e., clean hot water) is utilized to heat the buildings through the substation heat exchangers. The well head temperatures of the production wells vary from 62 to 99°C, while the volumetric flow rates of the wells range from 36 to 576 m$^3$/h. Geothermal fluid is sent to the primary plate type heat exchanger (between the geothermal fluid and the district heating water) and is cooled to about 38-42°C, as its heat is transferred to the district heating water. The geothermal fluid is discharged via natural direct discharge and reinjected (reinjection studies are expected to be completed in the near future). The temperatures obtained during the operation of the Salihli GDHS are, on average, 86-88/38-42°C for the district heating distribution network and 56-57/40-42°C for the building circuit. By using the control valves for flow rate and temperature at the building main station, the needed amount of water is sent to each housing unit and the heat balance of the system is achieved. Geothermal fluid collected from the production wells at an average well heat temperature of about 86°C, is pumped to the inlet of the heat exchanger mixing tank, a main collector (from four production wells) with a total mass flow rate of about 175 kg/s [3-5].

3 Analysis

Authors apply thermoeconomic model developed by [12] to GDHSs. Detailed energy and exergy losses calculations methods can be identified directly from [3,4]. For convenience, the energy loss rate for a system is denoted in the present analysis as $\dot{L}_{en}$, (loss rate based on energy). As there is only one loss term, the “waste energy output,” in Eq. (1)

$$\dot{L}_{en} = \text{Waste energy output rate}$$

Exergy losses can be identified from the exergy balance in Eq. (2). There are two types of exergy losses: the “waste exergy output”, which represents the loss associated with exergy that is emitted from the system, and the “exergy consumption”, which represents the internal exergy loss due to process irreversibilities. These two exergy losses sum to the total exergy loss. Hence, the loss rate based on exergy, $\dot{L}_{ex}$ is defined as [12]

$$\dot{L}_{ex} = \text{Exergy consumption rate} + \text{Waste exergy output rate}$$

The capital cost is defined here using the cost balances in Eq. (3) is denoted by K. Capital cost is simply that part of the cost generation attributable to the cost of equipment:

$$K=\text{Capital cost of equipment}$$

The principal reason that capital costs are used here is that the use of the cost generation term increases significantly the complexity of the analysis, since numerous other economic details (interest rates, component lifetimes, salvage values, etc.) must be fully known. There are two main justifications for this simplification [12]:

- Capital costs are often the most significant component of the total cost generation. Hence, the consideration of only capital costs closely approximates the results when cost generation is
• Cost generation components other than capital costs often are proportional to capital costs. Hence, the trends identified in the present work will likely be in qualitative agreement with those identified when the entire cost generation term is considered.

For a thermal system operating normally in a continuous steady-state steady-flow process mode are assumed. Hence all losses are associated with the already discussed terms \( \dot{L}_{\text{en}} \) and \( \dot{L}_{\text{ex}} \). The energy and exergy loss rates can be obtained through the following equations [12]:

\[
\dot{L}_{\text{en}} = \sum_{\text{inputs}} \dot{E} - \sum_{\text{products}} \dot{E} \tag{4}
\]

and

\[
\dot{L}_{\text{ex}} = \sum_{\text{inputs}} \dot{E} - \sum_{\text{products}} \dot{E} \tag{5}
\]

where the summations are over all input streams and all product output streams.

Another parameter, \( R \), is used as the ratio of thermodynamic loss rate \( \dot{L} \) to capital cost \( K \) as follows [12]:

\[
R = \frac{\dot{L}}{K} \tag{6}
\]

The value of \( R \) generally depends on whether it is based on energy loss rate in which case it is denoted \( R_{\text{en}} \), or exergy loss rate \( R_{\text{ex}} \), as follows:

\[
R_{\text{en}} = \frac{\dot{L}_{\text{en}}}{K} \tag{7}
\]

and

\[
R_{\text{ex}} = \frac{\dot{L}_{\text{ex}}}{K} \tag{8}
\]

4 Results and Discussion

Energy-efficient utilization, as well as careful monitoring and modeling of Turkish GDHSs, are essential ingredients in sustainable development. Reinjection is also essential for sustainable utilization of GDHSs, which are virtually closed and with limited recharge. Eq. [] illustrates old and new thermoeconomic correlations of SGDHS.

The old thermoeconomic correlation[7]:

\[
R_{\text{ex}}(T) = 0.173e^{-0.01367a} \tag{9}
\]

The new thermoeconomic correlation [3]:

\[
R_{\text{ex}}(T) = 0.153e^{-0.01677a} \tag{10}
\]

5 Conclusions

It is also observed that automatic control of the GDHSs components and process in general will reduce the losses and human involvement and make the system more effective and efficient.

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