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Performance assessment of a novel hybrid district energy system

C. Coskun [a], Z. Oktay [b,*], I. Dincer [c]

[a] Turgut Kiran Maritime College, Department of Marine Engineering, Recep Tayyip Erdogan University, Rize, Turkey
[b] Department of Energy Systems Engineering, Faculty of Engineering, Recep Tayyip Erdogan University, 10110 Rize, Turkey
[c] Faculty of Engineering and Applied Science, University of Ontario Institute of Technology (UOIT), 2000 Simcoe St. N., Oshawa, ON L1H 7K4, Canada

HIGHLIGHTS

► A new hybrid system is proposed for improving the efficiency of geothermal district heating systems (GDHSs).
► The average overall system efficiencies are increased by 7.5% for energy and 13% for exergy, respectively.
► Various energetic and exergetic parameters are studied.

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ABSTRACT

In this paper, a new hybrid system for improving the efficiency of geothermal district heating systems (GDHSs) is proposed. This hybrid system consists of biogas based electricity production and a water-to-water geothermal heat pump unit (GHPU), which uses the waste heat for both heating and domestic hot water purposes. Electricity generated by the biogas plant (BP) is utilized to drive the GDHS's pumps, BP systems and the heat pump units. Both the biogas reactor heating unit and the heat pump unit utilize the waste heat from the GDHS and use the system as a heat source. The feasibility of utilizing a hybrid system in order to increase the overall system (GDHS + BP + GHPU) efficiency is then investigated for possible efficiency improvements. The Edremit GDHS in Turkey, which is selected for investigation in this case study, reinjects 16.8 MW of thermal power into the river at a low temperature; namely at 40 °C. Such a temperature is ideal for mesophilic bacterial growth in the digestion process during biogas production. 1.45 MW of biogas based electricity production potential is obtainable from the waste heat output of the Edremit GDHS. The average overall system efficiencies through the utilization of this kind of hybridized system approach are increased by 7.5% energetically and 13% for exergetically.

1. Introduction

Geothermal energy is a renewable energy source and may in large be used for electricity generation, heating, cooling, industrial drying, fermentation, balneological purposes, as well as for distillation and desalination applications, depending on the temperature of the resource. Additionally, various combinations of these options may practically be employed [1].

District heating and power production are two common utilization forms of geothermal energy in practice. District heating is one of the most common and widespread direct uses of geothermal sources, and such systems are employed in order to provide space heating and/or cooling to multiple consumers from a single well or multiple wells/fields. When geothermal energy is used for residence heating, considerable fuel cost savings are achieved in comparison to the use of a conventional fossil-fuel district heating system. The environmental benefits of using geothermal sources in district heating may be quantified by calculating the reduction in greenhouse gas and air pollutant emissions compared to those emissions emitted from fossil fuels based systems. Protection of the environment is one of our most important obligations and goals serving this purpose were defined in a number of key UN Summits in Rio (1991), Kyoto (1997) and Johannesburg (2001). Any type of energy production, transportation, transformation, conversion and consumption has some impact on the environment and the magnitude of such an impact will depend closely on the technologies and the methods that were used. In addition, the budget savings that would be achieved through the utilization of geothermal sources for heating rather than diesel fuel, LPG, fuel-oil, electricity, domestic lignite coal, LNG, imported coal and natural gas may reach up to 50–90%.

There are numerous research studies available in the literature regarding geothermal energy utilization for district heating and

* Corresponding author. Tel.: +90 464 311 1071; fax: +90 464 311 1072.
E-mail addresses: dr.can.coskun@gmail.com (C. Coskun), zuhal.oktay@gmail.com, zoktay@yahoo.com (Z. Oktay), ibrahim.dincer@uoit.ca (I. Dincer).

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power production. Kanoğlu and Cengel [2] conducted an economic evaluation of geothermal power generation, heating, and cooling. Coskun *et al.* [3–5] investigated the geothermal district heating systems using new energy and exergy parameters. Borsukiewicz-Gozdur and Nowak [6] investigated maximizing the working fluid flow for increasing the power output of a geothermal power plant [7]. Nowak et al. [8] analyzed the possibilities for the implementation of absorption heat pumps in the application of the Clausius–Rankine cycle in geothermal power stations. Coskun et al. investigated the energetic and the exergetic performance evaluation of a geothermal power plant. Kanoglu [9] analyzed the dual-level binary geothermal power plants from an exergy perspective.

In the literature, a limited amount of application areas was proposed for the utilization of the waste heat from GDHS because of its relatively low temperature range (35–45 °C). Some of the practical and economical applications are listed as greenhouse heating, swimming pool heating, fish farm heating, biogas reactor heating and use in fermentation and distillation units. In addition, the given temperature range would be raised up to 60 °C using a heat pump system. Then, the available energy would be utilized in the district heating systems. One of the most effective ways to enhance the system's energy efficiency and the number of heated dwellings is to incorporate a heat pump system into the geothermal district heating system. The waste heat energy that is generated by GDSHs is a highly convenient source for HPs and it should be utilized in this regard for improving the overall system efficiency. Heat pump systems became a popular component of heating and cooling applications and many studies [13–21] investigated them from different perspectives. Hepbasli and Akdemir [10–12] investigated the energetic and exergetic performance of ground source heat pump systems experimentally. Hepbasli [13] also analyzed thermodynamically the utilization of ground-source heat pump systems for their use in district heating. Zhao et al. [14,15] conducted an experimental research on the performance of geothermal heat pump systems when different working fluids were used. Yang et al. [16] and Eslami-nejad et al. [17] investigated the performance of solar and heat pump hybrid systems. Modeling and thermal performance evaluation of ground source heat pump systems was investigated by many researchers [18–21]. Back [22] designed and analyzed the heat pump heating systems using wastewater as the heat source.

Heat pump systems are not competitive against natural gas alternatives due to the presence of only small scale applications in Turkey because of high electricity prices. Nevertheless, the price of the supplied electricity should be lowered in order to extend the widespread utilization of such systems. Two options are available for attaining a lower price on electricity supply for HP systems. The first is to implement government incentives, while the second is to produce electricity at lower costs using different methods. Biogas based electricity is a suitable option for generating low cost electricity in Turkey owing to the presence of strong agricultural, livestock and intense industrial activity. Turkey has a huge potential for biogas production from agricultural and industrial wastes; however, these resources cannot be effectively utilized to their full potential in an economically feasible manner [23]. It is known that biogas is the one of the significant alternative energy sources and its production output is based on the availability of potential biogas sources in the country. Different methods [24] employing aerobic and anaerobic activities may be used for the effective production of biogas from various raw materials, such as agricultural and industrial wastes. On the other hand, anaerobic biogas production processes have the advantage of low energy requirement for operation, low initial investment cost and low sludge production compared to the conventional aerobic processes [25].

There are two important considerations in the production of biogas from wastes. First issue is the transportation of waste and the second is to keep the biogas reactor at a constant temperature for more efficient biogas production. Transportation costs are also high due to the high diesel fuel price in Turkey. In order to supply biogas based electricity at a competitive price level, electrical vehicles could be used in the transportation of wastes to biogas reactors. In conjunction with this, biogas production systems should be designed by taking into consideration the related electricity requirement of the electrical vehicles. The excess electricity that would be produced should be utilized by the GDHS pumps (for purposes of circulation, well head, and reinjection) and the electrical vehicle charging units. The second important consideration is the heating of the biogas reactor. GDHS produced waste heat may be utilized for keeping the biogas reactor at a constant temperature. Alkhamis et al. [26] tested the biogas reactor heating by utilizing a solar energy system. One of the most important advantages of geothermal energy is supplying a constant energy output without any fluctuations in contrast to the energy production by other renewable energy sources such as wind and sun.

Kreuter and Kapp [27] reported hybrid geothermal and biogas power plants. This hybrid concept was developed in order to help a community in the Upper Valley. This project is now being implemented in the village of Neuried for the first time worldwide. In a fermentation process, methane is produced and then combusted in gas engines. These engines drive a generator, which feeds electricity into the grid. With the help of a heat exchanger, the heat of both the mufflers and the cooling system of the engines are fed into the power-producing cycle of the geothermal power plant.

In this paper, a new hybrid system for geothermal district heating systems (GDHS) is proposed in order to improve the efficiency for practical applications. In this regard, both energy and exergy efficiencies are studied for comparison purposes, in addition to various energetic and exergetic parameters that are studied here. The present hybrid system is expected to be more environmentally friendly and sustainable in practice.

2. Description of the Edremit GDHS

The population of Edremit is 49112. The Edremit GDHS is designed as having 3 stages with a total capacity ultimately corresponding to 7500 dwelling equivalences. In this manuscript, a feasibility study of incorporating a heat pump system into a geothermal district heating system was investigated in order to increase the resident number utilizing geothermal energy for both heating and domestic hot water purposes through the utilization of low temperature discharged geothermal water as a heat source. This study aims to utilize the discharged geothermal water to contribute to sustainable development. Energy, which would be gained, will contribute to the protection of the natural resources by reducing the use of the fossil fuels and the environmental would also benefit via the decrease in the amount of the emissions of greenhouse gasses.

The Edremit geothermal field is located 87 km west to the Balikesir Province, which is located in the Northwestern Anatolia. Edremit GDHS is operational since 2003 and is still under development. The geothermal source is 3–4 km away from the center of Edremit. There are seven wells in the geothermal field, with depths ranging from 195 to 496 m. The mass flow rates of the operating wells range from 18 kg/s to 86 kg/s. Geothermal fluid collected from the three production wells, which have an average wellhead temperature of 60 °C, is pumped to the heat exchangers built under the buildings. The geothermal fluid enters the heat exchanger at an average temperature of 58–59 °C and here, the heat is transferred to the fresh water flowing through those heat exchangers. At this point, the geothermal fluid, after being used, is discharged to the Edremit river at an outlet temperature of 40–42 °C. Further details