Energy 94 (2016) 391–400

Contents lists available at ScienceDirect

Energy

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

Exergoenvironmental analysis for a geothermal district heating system: An application

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A R T I C L E I N F O

Article history:
Received 21 July 2015
Received in revised form
9 October 2015
Accepted 3 November 2015
Available online 28 November 2015

Keywords:
Geothermal energy
District heating system
Exergy analysis
LCA analysis
Exergoenvironmental analysis
Environmental performance

A B S T R A C T

Energy sources are of great importance in relation to pollution of the world. The use of renewable energy resources and the creation of more efficient energy systems make great contributions to the prevention of greenhouse gases. Recently, many studies indicate that the energy conversion systems have many advantages in terms of technical and economic point of view. In near future, environmental impact is going to play an important role in the selection/design of such energy resources and systems. In this study, the Afyon GDHS (geothermal district heating system) having actual operating conditions is investigated at the component level in terms of environmental impact by using exergoenvironmental analysis. Moreover, the effects of ambient and wellhead temperatures on the environmental impacts of the system are discussed. The results show that a great part of total environmental impact of the system occurs from the exergy destructions of the components. Therefore, the environmental impacts can be reduced by improving their exergetic efficiencies instead of design changes of the system components. The environmental impacts of the system are reduced when the ambient temperature decreases and the wellhead temperature increases. Thus, it might not be necessary to conduct separately the exergoenvironmental analysis for different ambient temperatures.

1. Introduction

Energy engineers try all kinds of ways of preventing the end of the world despite limited energy sources of the world, economic crises and negative environmental impacts. One of these ways is to develop more efficient energy conversion systems. In this way, the amount of the consumed fuel and all the relevant environmental impact especially the emission of carbon dioxide, one of the basic components of greenhouse gases, can be reduced. As a result of continuous increasing of energy demand and environmental problems, the research on energy conversion technologies to develop new, clean and renewable energies is also increasing; particularly on geothermal energy and technologies. However, many countries including Turkey have made recently political decisions to use natural gas and its technology which can be supplied easily for power generation and space heating [1].

However, the economic and environmental competition of geothermal energy is still at a critical point. Thus, as an alternative source of fossil energies and a way of contributing to the reduction of environmental pollution, the interest in geothermal energy and its technology is increasing. On the World, geothermal energy is generally used for two purposes. One of them is electricity generation and the other one is direct use. The focus of the current study, direct use of geothermal energy is preferred because of its rapid use as heat energy rather than its conversion to electric energy. Primary ways of the direct use are space heating and cooling [2]. Lund and Tonya [3] investigated the general case of geothermal energy worldwide for the direct use in the World Geothermal Congress hold in 2015. In the World, the installed power and used thermal energy amounts at the end of 2014 have reached, respectively, 70 GW_t and 587,786 TJ/yr with the increase with 45% and 38.7% when compared to the 2010 year. Nearly 15% of this thermal energy (88,222 TJ/yr) is used for space heating and 89% of the energy used for space heating is involved in district heating. The countries having the highest installed geothermal power as a direct use of geothermal energy are China, USA, Sweden, Turkey and Germany accounting for 65% of the total production. In addition, the countries consuming the most geothermal energy for district heating annually are China, Iceland, Turkey, France, and Germany; on the other hand, Turkey, USA, Italy, Slovakia and Russia are countries using the most geothermal energy for individual space heating.

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http://dx.doi.org/10.1016/j.energy.2015.11.010
0360-5442/

Turkey is among the first five countries in terms of the direct use of geothermal energy. More than 225 geothermal fields have been determined in Turkey and these fields have temperatures varying between 20 and 287 °C. The number of the geothermal wells that have been drilled so far for exploratory, production and reinjection purposes is about 1200 in Turkey. Now, the number of the actively operating geothermal district heating systems in which heat pumps are not used is 16. The number of user making use of these systems is 77,453 residences. The total installed capacity is 2886.3 MW_t and 45,126 TJ/yr for annual energy use. The values related to the installed capacity and annual energy use for the various direct-use applications are: 420 MW_t and 4635 TJ/yr for individual space heating and 805 MW_t and 8885 TJ/yr for district heating [4]. In this case, the ratio of geothermal energy use is gradually increasing and it is replacing other resources of energy, particularly the fossil fuels. In many countries, dependence on imported fuels is decreasing [3]. Thus, it reduces the amount of pollutants dumped to the environment such as greenhouse gases and particulate matters. Energy savings resulting from the use of geothermal energy in terms of fossil fuel consumption equal to 350 million barrels of oil annually; thus, 46 million tonnes of carbon and 148 million tonnes of CO_2 are prevented from being released to the atmosphere.

Advances in technology can be created with the existing energy conversion systems which makes it better for higher energy efficiency and lower environmental impact. Energy and environmental impacts of thermal conversion systems can be divided into two categories: (i) indirect impacts stemming from the use of renewable energy sources instead of other energy sources, especially the use of geothermal energy in this study, and (ii) direct impacts resulting from embodied energy of thermal energy systems. In open literature, the use of geothermal energy instead of energy resources harmful to environment (fossil fuels) has been reported to have some positive effects on environment.

Because of the progress in the direction of thermal system technologies with low or near zero embodied energy, the carbon emissions resulting from their use has been minimized. In this way, it should be given priority in controlling and reducing the environmental impacts of all the production chain of thermal system technologies. The increased investment in new and improved thermal system materials promotes attempts to find positive solutions to economic and environmental problems through thermal systems. Thus, the contribution of these materials has been gained momentum to life cycle environmental impact. In addition to this, the development of geothermal energy technologies or enhancing their efficiency can make contributions to the protection of environment.

Exergy analysis is very useful in evaluating the quality of a source and determining thermodynamic inefficiencies. Inefficiencies in thermal systems can be minimized through the low exergy or exgery-efficient systems. Exergy loss leads to environmental impacts. In the evaluation of the direct impacts caused by the embodied energy of thermal systems to environment, the LCA (life cycle assessment) is the most suitable methodology that can be apply for calculating environmental impacts that occur throughout the entire life span [5,6]. Furthermore, exergoenvironmental analysis is a suitable combination of exergy analysis [7] and LCA [5,6]. Here, the environmental impacts obtained by LCA are assigned into exergy flows. Thus, these flows show the main system components having the greatest environmental impact and possible development associated with these components [8].

Exergoenvironmental analysis is a relatively new method but it has been widely used to evaluate the environmental impacts of many energy conversion systems. Meyer et al. [8], used this method for the first time, presented the general methodology of exergoenvironmental analysis on high-temperature solid oxide fuel cell. They evaluated the environmental impacts of the system components in terms of the component-related and the exergy destruction. Moreover, they reported the restrictions of the LCA as an environmental evaluation method. Boyano et al. [9] dealt with exergoenvironmental analysis of the vapor methane reform process for hydrogen production. They evaluated the environmental impacts of the conducted system according to the component-related, exergy destruction and pollutant formation. They reported that the highest amount of environmental impact results from exergy destruction and most of the total environmental impacts are related to chemical reactor. Petrakopoulou et al. [10] studied the exergoenvironmental analysis of a combined cycle plant using the chemical looping combustion technology. In their study, the oxy-fuel power plant with 100% CO_2 capture and without CO_2 capture were compared according to the environmental impacts of the component-related and the exergy destruction. In another study, Petrakopoulou et al. [11] compared the oxy-fuel power plant with 85% and 100% CO_2 captures and without CO_2 capture by using exergoenvironmental analysis. Banerjee and Tierney [12] employed five different exergoenvironmental methods to analyze the environmental impacts of various energy technologies in rural areas of developing countries. These methods are waste (or destroyed) exergy method, thermo-ecological cost method, extended exergy accounting, extended thermoeconomics and combining exergetic analysis with the environmental indicator (or exergoenvironmental). The most effective method was found to be exergoenvironmental analysis.

In recent years, Atılgan et al. [13] considered the exergoenvironmental analysis of turboprob engine used in district airplanes. They evaluated the environmental impacts of the engine components on the component-related and exergy destruction. They reported that the first thing to be done is to improve the combustion chamber of the engine from environmental impact point of view. Abusoglu and Sedeeq [14] investigated the environmental performance of the heating systems such as traditional coal boiler, condensing natural gas combi boiler and underground source heat pump used in the construction sector in Turkey. The best heating system in terms of environmental impact was found to be condensing natural gas combi boiler. Blanco-Marigorta et al. [15] conducted the exergoenvironmental analysis by using actual operational data for reverse osmosis sea water purification plant in Gran Canaria (Canary Islands, Spain). Hamut et al. [16] performed the exergoenvironmental analysis of hybrid electrical vehicle thermal direction system. The component having the highest environmental impact was found to be electric battery. Manesh et al. [17] performed the exergoenvironmental analysis of gas fired steam power plant with a total site utility system.

As can be seen in the above-mentioned studies, there is no study reported in the literature on the exergoenvironmental analysis and evaluation of geothermal district heating system through life cycle assessment analysis. The purpose of the current study is to investigate the environmental impacts and performance of a geothermal based district heating system by using exergoenvironmental analysis. In this study for the first time, the potential of reducing the environmental impacts of system components is determined by means of exergoenvironmental relations and actual data. Moreover, the study addresses the effects of ambient and wellhead temperatures on the environmental impacts of the system components.

2. Definition of the system

The Afyon GDHS (geothermal district heating system) went into service in the city of Afyonkarahisar/Turkey in 1994 for the heating of buildings with geothermal fluid. Since then, it has been modified once. This system with 102 MW_t heating capacity was designed for 10 thousand residences. Geothermal fluid of the Afyon GDHS is