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Energy and exergy analysis of a ground-coupled heat pump system with two horizontal ground heat exchangers

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Abstract

In this paper we investigate of energetic and exergetic efficiencies of ground-coupled heat pump (GCHP) system as a function of depth trenches for heating season. The horizontal ground heat exchangers (HGHEs) were used and it were buried with in 1 m (HGHE1) and 2 m (HGHE2) depth trenches. The energy efficiency of GCHP systems are obtained to 2.5 and 2.8, respectively, while the exergetic efficiencies of the overall system are found to be 53.1% and 56.3%, respectively, for HGHE1 and HGHE2. The irreversibility of HGHE2 is less than of the HGHE1 as about 2.0%. The results show that the energetic and exergetic efficiencies of the system increase when increasing the heat source (ground) temperature for heating season. And the end of this study, we deal with the effects of varying reference environment temperature on the exergy efficiencies of HGHE1 and HGHE2. The results show that increasing reference environment temperature decreases the exergy efficiency in both HGHE1 and HGHE2.

Keywords: Ground coupled heat pump; Horizontal ground heat exchanger; Energy analysis; Exergy analysis

1. Introduction

The use of ground-coupled heat pumps (GCHPs) in commercial and residential facilities is a remarkable example. GCHP systems exchange heat with the ground, and maintain a high level of performance even in colder climates. This results in more efficient use of energy, for this reason many society utilities support the use of GCHP systems. The first patent on using ground as a heat source for GCHP systems, issued in Switzerland in 1992, is due to Heinrich Zoley. This date may be regarded as the official date of birth of GCHP systems, but the concept of using the ground as a heat source is much older [1].

In history, there has been a noticeable increase of interest in the applications second law analysis to the design of thermal systems [2]. A typical thermal design based on the first law thermodynamics allows us to address issues related to the energy balance of the system. The second law of thermodynamic analysis combined with a standard design procedure of a thermal system gives us invaluable insight into the operation of the system. Exergy (or availability) analysis is a powerful tool in the design, optimization and performance evaluation of energy systems. This analysis can be used to identify the main sources of irreversibility (exergy loss) and to minimize the generation of entropy in a given process where the transfer of energy and material take place [3,4]. According to Dincer and Rosen [5], exergy analysis is an effective thermodynamic scheme for using the conservation of mass and energy principles together with the second law of thermodynamic for the design and analysis of thermal systems, and is an efficient technique for revealing whether or not and by how much it is possible to design more efficient thermal systems by reducing the inefficiencies. The concepts and definitions of exergy analysis are well recognized [6–9].

Various theoretical [10–13] and experimental [14–18] studies based on the exergy concept with heat pump systems have been published. Nakanishi et al. [10] investigated exergetic performance of various heat pump units. Hiharat [11] has been carried out theoretically heat

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Nomenclature

$COP_{overall}$	heating coefficient of performance of ground coupled heat pump system (−)
$C_{p,air}$	specific heat of air (kJ/kg K)
$C_{p,wa}$	specific heat of water–antifreeze solution (kJ/kgK)
$\dot{E}$	energy rate (kW)
$\dot{E}x$	exergy rate (kW)
$\dot{F}$	exergy rate of the fuel (kW)
h	specific enthalpy (kJ/kg)
$\dot{I}$	rate of irreversibility (kW)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (Bar)
$\dot{P}$	exergy rate of the product (kW)
$\dot{Q}$	heat transfer rate (kW)
s	entropy (kJ/kg K)
T	temperature (°C)
$\dot{W}$	work rate or power (kW)

Greek letters

ε	exergy (second law) efficiency (dimensionless)
ψ	specific exergy (kJ/kg)

Subscripts

0	dead state
act	actual
comp	compressor
cond	condenser
cp	circulating pump
cfan	condenser fan
ct	capillary tube
d	destroyed, destruction
e	entropy
eva	evaporator
gen	generation
ghe	ground heat exchanger
HE	heat exchanger
i	inlet
o	outlet
overall	system
ref	refrigerant
r	location
tot	total
wa	water–antifreeze

Superscripts

CH	chemical
εx	specific exergy (kJ/kg)
KN	kinetic
PH	physical
PT	potential

pump systems and analyzed each transformation from the exergetic point of view. Bejan [12] studied theoretically refrigeration systems and investigated based on entropy generation minimization. The study can be used for the thermodynamic optimization of refrigeration plants. Yumrutas et al. [13] studied exergy analysis of vapor compression refrigeration systems. A computational model based on the exergy analysis was presented for the investigation of the effects of the evaporating and condensing temperatures on the pressure losses, the exergy losses, the second law of efficiency, and the coefficient of performance (COP) of a vapor compression refrigeration cycle. Kaygusuz and Ayhan [14] presented experimentally a solar assisted heat pump system, and analyzed the data using exergy idea. Torres-Reyes et al. [15,16] studied a solar assisted heat pump experimentally, and optimized the system using exergy analysis. Bridges et al. [17] presented a second law analysis of domestic refrigerator and air-conditioning systems quantifies the destruction of available energy in each component to contribute to overall system efficiency. Smith and Few [18] presented second law analysis of an experimental domestic scale cogeneration plant incorporating a heat pump. The use exergy analysis in this work significantly contributed to the development of the combined heat and power plant concept. Bilgen and Takahashi [19] had been carried out exergy analysis of heat pump–air conditioner systems. The irreversibilities due to heat transfer and friction had been considered. Based on the exergy analysis, a simulation program had been developed to simulate and evaluate experimental systems. Badescu [20] investigated first and second law analysis of a solar assisted heat pump based heating system.

The studies on exergy analysis of GCHPs are relatively few. Piechowski [1] studied a relatively new approach to optimisation of a ground heat exchanger (GHE), based on the second law of thermodynamics and was adopted to test for an optimum combination of circulating water flow rate and pipe diameter. This method allows for identification and quantification of irreversibility taking place during a GHE operation. Hepbasli and Akdemir [21] described energy and exergy analysis of a GCHP system. The exergy transports between the components and the consumptions in each of the components of the GCHP system were determined for the average measured parameters obtained from the experimental results in February 2001. Ozgener and Hepbasli [22] investigated to the performance characteristics of a solar assisted GCHP greenhouse heating system with a 50 m vertical 1 × 1/4 in. nominal diameter U-bend GHE using exergy analysis method. Exergetic efficiencies of the system components were determined in an attempt to assess their individual performances and the potential for improvements was also presented.