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ScienceDirect

Solar Energy 134 (2016) 95–106

SOLAR ENERGY

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Energy and exergy analyses of a new geothermal–solar energy based system

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Received 30 March 2015; received in revised form 12 March 2016; accepted 17 April 2016
Available online 6 May 2016

Abstract

This paper deals with a new multigeneration system which is primarily powered by renewable energy, geothermal energy and assisted with solar energy. This multigeneration system consists of a single flash geothermal cycle, heat pump system, single-effect absorption cooling system, thermal energy storage connected with auxiliary steam turbine, hot water system and drying system. The aim of this system is to produce five output commodities; refrigeration for industry, heating air for residential application, hot water for domestic use, drying food and finally electricity. The system is assessed both energetically and exergetically. The overall energy and exergy efficiencies are found to be 69.6% and 42.8% respectively. The effects of changing various system parameters on energy and exergy efficiencies of the overall system and its subsystems are examined accordingly.

Keywords: Solar energy; Geothermal power; Multi-generational systems; Exergy analysis; Efficiency

1. Introduction

A heavy use of fossil fuels has resulted in two main concerns: fundamentally over their sustainability and their environmental and health impacts. The emissions of harmful gasses and particulates, including CO_2, NO_x, SO_x, etc., which cause considerably serious problems for nature, human beings and the environment. Accordingly, using alternate sources of energy, especially if derived from nature itself, such as; solar, wind and geothermal will be more convenient and a rescue solution from fossil fuels era on the long term.

According to EIA (2014), the production of energy from renewable resources in the USA has, for example, increased more than three times since 1950 until 2013 from 3142 EJ to 9810 EJ. The shares of geothermal, solar and wind are 233 EJ, 323 EJ and 1683 EJ respectively. The statistics of 2014 provide a key promise as they show a higher production for the first nine months compared with 2013. Note that an amount of 9810 EJ is distributed as generating electric power (with 5 EJ), industrial application (with 2.32 EJ), transportation (with 1.37 EJ), residential applications (with 0.84 EJ) and commercials (with 0.1 EJ), respectively.

IEA (2014) stated that the use of renewable power increased tremendously for the last few years and expected to grow more in the future. Currently renewable power generation reached almost 22% of the global mix, compared with 21% in 2012 and 18% in 2007. It also asserts that the share of renewables in electricity production in

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http://dx.doi.org/10.1016/j.solener.2016.04.029
0038-092X/

Nomenclature

$\dot{E}$	exergy rate (kW)
E	exergy of flow (kJ)
ex	specific exergy (kJ/kg)
En_{acc}	energy accumulation (kJ)
Ex_{acc}	exergy accumulation (kJ)
Ex^{Q}	thermal exergy (kJ)
Ex_{d}	exergy destruction (kJ)
$\dot{E}x^{Q}$	thermal exergy rate (kW)
$\dot{E}x_{d}$	exergy destruction rate (kW)
H	enthalpy of flow (kJ)
h	specific enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
$\dot{Q}$	heat rate (kW)
Q	heat (kJ)
s	specific entropy (kJ/kg K)
$\dot{s}_{gen}$	entropy generation rate (kW/K)
T	temperature (K)
$\dot{W}$	work rate (kW)

Greek letters

η	energy efficiency
ψ	exergy efficiency

Subscripts

0	reference environment
1,2,...,40	state points
Abs	absorption chiller
Comp	compressor
Cond	condenser
COP	coefficient of performance
Dry	dryer
Eva	evaporator
sol	solar energy input
F	fan
Gen	generator
HE	heat exchanger
hp	heat pump
ha	hot air
hw	hot water
L	loss
O	overall
P	pump
P_r	product
s	source
st	steam turbine
Sol	solar
TES	thermal energy storage
Wa	water
X	vapor quality

OECD countries steadily increased from 17.3% in 1990 to 21% in 2013. Most of the growth was primarily observed in the use of wind, solar and geothermal energies.

The benefit of the solar energy is that it provides energy without any environmental pollution and can be sustainable. In addition, solar energy industry has grown and the obstacle of high prices of the solar energy systems components has come finally to an end due to the tremendous increase of its usage (Kalogirou, 2013). The other type of renewable energy that is most common is geothermal energy. There are generally three types of geothermal fields based on temperature range namely hot water, wet steam and dry steam fields (Guo et al., 2011; Hettiarachchi et al., 2007).

One of the ways to make the system more efficient is by using the approaches of cogeneration and multigeneration as designated by Dincer and Rosen (2013). Dincer and Zamfirescu (2012) stated that multigenerational systems can provide better efficiency, cost-effectiveness, environment and hence better sustainability. A lot of work done towards energy and exergy analyses of multi-generation systems. Espirito Santo (2014) conducted energy and exergy analyses of combined heating, cooling and power generation system and the results of energy efficiencies were between 58% and 77%, while exergy efficiencies were ranging between 35% and 41%.

Esfahani and Yoo (2013) proposed three power and fresh water cogeneration systems, an exergy analysis of the three systems was carried out by them. Their results showed that the cogeneration system with the absorption chiller is found to be the best. Since it can increase exergy, energy efficiencies and net power generation by 3.79%, 4.21%, and 38%, respectively, compared to the base system. El Emam and Dincer (2013) performed thermodynamic and economic analyses of a geothermal regenerative organic Rankine cycle based on both energy and exergy analyses. The energy and exergy efficiencies values are found to be 16.37% and 48.8%, respectively. The mass flow rates of the organic fluid, cooling water and provided geothermal water are calculated for a net output power of 5 MW.

Khalid et al. (2015) combined two energy sources solar and biomass to develop multi-generation system which provide multiple commodities and the performance of the system is evaluated. Moreover, a parametric study is carried out to reveal the effect of different parameters on the energy and exergy efficiencies of the system. The overall energy and exergy efficiencies of the system are found to be 66.5% and 39.7% respectively. Malik et al. (2015) developed and studied a multigeneration system energetically and exergetically. The system is based on two renewable sources of energy, biomass and geothermal, both sources