Energy xxx (2014) 1–9

Contents lists available at ScienceDirect

Energy

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

Development of an integrated renewable energy system for multigeneration

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ARTICLE INFO

Article history:
Received 29 May 2014
Received in revised form
23 September 2014
Accepted 30 September 2014
Available online xxx

Keywords:
Dryer
Efficiency
Exergy
Geothermal
Multigeneration
Solar

ABSTRACT

In this paper, we propose a new integrated, solar and geothermal energy based system for multigeneration applications, which comprises two ORC (organic Rankine cycles) for power generation, an absorption chiller cycle for cooling production and a drying system to dry wet products. In addition, some useful heat is recovered from the condensers of the ORC for heating applications. In order to determine the irreversibilities, almost all the system components are examined energetically and exergetically. The overall energy and exergy efficiencies of the system are found to be 54.7% and 76.4%, respectively. Moreover, to analyze the system efficiently, parametric studies are also performed to observe the effects of different substantial parameters namely inlet pressure and temperature of the ORC turbine, and reference environment temperature in order to investigate the variations in the system performance in terms of the energy and exergy efficiencies.

1. Introduction

The energy challenges in the last few decades and the environmental issues around the globe have been pushing many countries to provide incentives for promoting renewable energy source exploitation so as to replace or minimize the use of fossil fuels which emit pollutants and large amounts of carbon dioxide. Natural resources, for instance, sunlight, wind, rain, tides, waves, geothermal heat and biomass are otherwise also known as renewable energy resources. These are naturally refilled once used [1]. Vast portions of renewable electricity production are an encouraging opportunity to address global warming and the growing insufficiency of hydrocarbon fuels [2].

Solar energy is treated as universal energy source and sustainable. It is essentially the main source of various forms of energy, such as thermal (heat and radiation), hydropower (through hydrologic cycle), kinetic (for wind power) and biomass (for food and power) [3]. This abundant availability makes solar energy less costly with no pollution [4]. In addition, solar energy can be used to obtain power indirectly through a solar thermal system. Furthermore, different solar thermal systems namely PTSC (parabolic trough solar collector), solar dishes and solar tower are available to convert solar energy into useful output such as power generation. Amongst these solar thermal technologies for power production, PTSC systems are the most advanced technology and have been utilized in big power plants since the 1980s [5]. Based on this, PTSC technology was considered for raising the temperature of the heat transfer fluid used in this study.

Geothermal energy is also considered as a renewable and environmentally friendly source of energy. From the time geothermal energy was discovered, its usage has increased more than twice as noted by several researchers [6]. Geothermal energy sources are commonly divided into three categories on the basis of their source temperatures into a low-temperature source (less than 90 °C), a moderate-temperature source (between 90–150 °C) and a high-temperature source (above 150 °C) [7]. Moreover, efficient utilization of lower geothermal wells of about 70–100 °C is under intensive investigation. Wells with these temperatures are available in many places of the world; hence, progress in using them will provide vast potential for geothermal based ORC (organic Rankine cycle) units to produce power. To accomplish this, effective and efficient heat exchangers must be in place to minimize heat losses [8]. In many geothermal reservoirs, however, the water temperatures are moderate (60% steam liquid mixture) and not hot enough to produce steam with the force needed to efficiently run a turbine.

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http://dx.doi.org/10.1016/j.energy.2014.09.082

Nomenclature

COP	coefficient of performance
$\dot{E}$	exergy rate (kW)
ex	specific exergy (kJ/kg)
h	specific enthalpy (kJ/kg)
HEX	heat exchanger
HTF	heat transfer fluid
$\dot{m}$	mass flow rate (kg/s)
ORC	organic Rankine cycle
P	pressure (kPa)
PTSC	parabolic trough solar collector
$\dot{Q}$	heat rate (kW)
R	refrigerant
s	specific entropy (kJ/kgK)
T	temperature (K)
v	specific volume (m^3/kg)
$\dot{W}$	work rate (kW)

Greek symbols

η	energy efficiency
ψ	exergy efficiency

Subscripts

abs	absorber
avg	average
cond	condenser
dest	destruction
En	energy
eva	evaporator
Ex	exergy
geo	geothermal
gen	generator
p	pump
prod	product
s	source
t	turbine
1, 2…30	state numbers

Nonetheless, such moderate temperature reservoirs can generate electricity using an ORC. Organic Rankine cycles are economically promising technology to decrease investment costs at lower scale. They can produce power at low temperatures, and the total installed power can be scaled down to kW levels [9].

In multi-generation, a system produces several products such as electricity, heating, cooling and drying simultaneously. Multi-generation consumes the waste heat of a power plant to improve overall thermal performance, basically consuming the “free” energy available via the waste energy [10]. A lot of work has been done on multi-generation. In their study Al-Sulaiman et al. [11] showed that the maximum electrical energy efficiency was 14%; however, when trigeneration was used, the energy efficiency increased up to 94%. Ahmadi et al. [12] developed a biomass based integrated multi-generation system in which both thermoeconomic and multi-objective optimization studies are undertaken. In that system, exhaust gases from ORC turbine are utilized in heating process as well as to produce cooling using a double-effect absorption chiller. They integrated a biomass combustor, an ORC, a double effect absorption chiller and a desalination unit which have numerous benefits including higher efficiencies, reduced operating cost, thermal losses and wastes. Al-Zaharani et al. [13] proposed a multi-generation system by cascaded supercritical carbon dioxide (CO_2) Rankine cycle with Organic (R600) Rankine cycle for power generation, hydrogen production and space heating. Renewable geothermal heat was used as an energy source to operate the Rankine cycle, which helped reduce greenhouse gas emissions. Moreover, the multigeneration system with geothermal energy offered overall energy and exergy efficiencies of 13.67% and 32.27%, respectively and the overall exergetic effectiveness was 43.22% which provided the total net power for the base case of about 18.59 MW.

Ozturk and Dincer [14] assessed a solar-based multigeneration system with coal gasification, for producing power, heating, cooling, hydrogen, oxygen and hot water. Their multigeneration system comprises a coal gasification integrated with solar power energy. Energy and exergy efficiencies of the sub-system are changes from 20% to 46% respectively. While introduced multigeneration system gives a maximum energy efficiency of 54% and exergy efficiency as 58%. The combination of renewable solar energy and fossil coal gasification along with multi-generation has improved the performance of the system in terms of efficiency. Moreover, Al-Ali and Dincer [15] studied multigeneration system which has given great benefit by increasing energy efficiency by 78% whereas single generation was providing only 16.4%. In case of exergy efficiency, about 10% increased can be seen when system moved from single generation to multi-generation. The literature review suggests that multigeneration may be an advantageous option to reduce greenhouse gas emissions and increase efficiency.

Integrating the best of two renewable energy sources can improve overall power output. The integrated systems can increase the overall efficiency of a conventional plant up to 70% by providing useful outputs such as cooling, heating (and hot water) [16,17]. In this regard, the key specific objectives for this study are listed as follows:

- A new integrated, solar and geothermal based system for multigeneration is developed and analyzed in detail through energetic and exergetic approaches.
- Energy and exergy efficiencies of all subunits, subsystems and overall system are determined and comparatively assessed.
- Energy losses and exergy destructions are calculated for all major components to investigate the possibility of improving the proposed system.
- A parametric study is undertaken to investigate the effects of varying surrounding and operating conditions and state properties on the performance of the proposed system.

2. System description

This multi-generation system comprises a solar system to raise the temperature of the HTF (heat transfer fluid), two ORCs to produce electricity, a geothermal source to run one of the ORC, an absorption chiller for cooling, and a heat exchanger to produce hot dry air for drying purposes. The system is illustrated in detail in Fig. 1. In order to ensure an efficient ORC, its working fluid must have a high critical temperature [5]. In this study isobutane is used as working fluid in both ORC's so that more heat can be transferred from the solar and geothermal system to the working fluid. For low to medium temperature Organic Rankine cycles hydrocarbons are suitable as working fluids, in which one of them is isobutane, which is easily available and has high thermal efficiency [18]. Moreover, Therminol VP-1 is used as the HTF in the solar collector. The

Please cite this article in press as: Suleman F, et al., Development of an integrated renewable energy system for multigeneration, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.09.082