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Development, analysis and performance assessment of a combined solar and geothermal energy-based integrated system for multigeneration

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ABSTRACT

In this paper, a novel solar and geothermal energy-based integrated multigeneration system is proposed for multigenerational product plan. The system includes two ORC (organic Rankine cycle) power turbines, two thermal energy storage systems, an absorption chiller, a heat pump for space heating and a drying system. The present system is analyzed thermodynamically through energy and exergy methodologies, and the performances of the systems and subsystems are assessed incorporating energy and exergy analyses specifically for four cases; single generation, cogeneration, tri-generation and multigeneration. Both exergy destruction and losses in sub-embodiments and hence in the overall system are determined. Several design parameters, including the mass flow rate and temperature of the geothermal fluid, turbine inlet pressure, and ambient conditions, are varied to evaluate their effects on energy and exergy performances. The energy and exergy efficiencies of this proposed system, while working on multigeneration mode, are found to be 51% and 62%, respectively, whereas these efficiencies on single generation mode are in the order of 22% and 54%, respectively. This proposed system is superior to conventional single-source-based systems.

1. Introduction

The natural sources of energy, like solar, wind, geothermal, biomass, rain and tidal, are treated as renewable. These energy sources are replenished naturally after use. The energy from the sun is considered both sustainable and renewable. In addition to this, solar thermal systems can essentially provide power indirectly. Solar concentrators like solar dishes, PTC (parabolic trough collectors) and solar towers convert solar energy into advantageous outputs like heating, cooling and electrical power. Numerous large power plants across the world are using PTC (parabolic trough collector) since 1980s (Al-Sulaiman et al., 2010). Therefore, in this study, PTC technology is selected for heating the heat transfer fluid. Several researchers have reported that the use of geothermal energy has been doubled since its discovery (i.e., Ratlamwala and Dincer, 2013).

Multigeneration processes offer great potential for high energy and exergy efficiencies, low operating expenditures and less pollutant emissions (Ahmadi et al., 2012b). The low efficiency of a single renewable energy based systems can be improved by integrating the solar and geothermal energies. Their integration has resulted in a more efficient system.

The geothermal production of heat and power depends on the depth of reservoirs. Hydrothermal systems with temperatures more than 453 K are found near the boundaries of plate tectonic. Intermediate temperatures with range 373–453 K and low temperatures below 373 K geothermal systems are also present in continental settings with/without hydrothermal resources (Anon., 2014a). On the basis of the temperature, geothermal energy sources can be categorized as; Low-temperatures below 363 K, moderate temperatures between 363–423 K and high temperatures above 423 K (Coskun et al., 2011). The geothermal fields can be exploited for both power generations and direct use of heat, under appropriate conditions. An intermediate geothermal heat source is selected for this study.

The binary plants including ORC (Organic Rankine cycles) and Kalina cycles have many different technical variations (Kalina and Leibowitz, 1989). In binary cycles, there is no contact between the turbine and hot geothermal fluid, instead it heats up and vaporizes a secondary fluid to run the turbine. The geothermal hot fluid and the ORC working fluid circulate in separate closed loops. The ORC (organic Rankine cycle) is applicable for the

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Nomenclature

C	compressor
D	diameter of pipe (m)
$\dot{E}x$	exergy rate (kW)
ex	specific exergy (kJ/kg)
H	total enthalpy of the flow
h	specific enthalpy (kJ/kg)
L	length of pipe (m)
ks	surface roughness of the pipe
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
$\dot{Q}$	heat rate (kW)
R	refrigerant
Re	Reynolds number
s	specific entropy (kJ/kg K)
T	temperature (K)
V	velocity (m/s)
v	specific volume (m^3/kg)
$\dot{W}$	work rate (kW)

Greek symbols

f	Darcy friction factor
ρ	density (kg/m^3)
ν	kinematic viscosity (m^2/s)
η	energy efficiency
ψ	exergy efficiency
ω	humidity ratio (kg_{water}/kg_{air})

Subscripts

a	charging water inlet state
abs	absorber
avg	average
b	charging water exit state
c	discharging water inlet state
chrg	charging
cogen	cogeneration
cond	condenser
d	discharging water exit state
dest	destruction
dis	discharging
en	energy
eva	evaporator
gen	generator
geo	geothermal
hp	heat pump
multigen	multigeneration
P	pump
prod	products
s	source
sep	flash separator
singen	single generation
st	storing
sup	superheater
t	turbine
trigen	tri-generation
0	reference environment
1, 2 ... 46	state number

Acronyms

CFD	computational fluid dynamics
COP	coefficient of performance
EGS	enhanced geothermal system
GMDH	group method of data handling
HEX	heat exchanger
HTF	heat transfer fluid
LiBr-H_2O	lithium bromide-water
ORC	organic Rankine cycle
PTC	parabolic trough collector
SLD	staggered line drive
TES	thermal energy storage

low-temperature geothermal resources. The binary geothermal cycle has zero emissions.

An integrated coal gasification multi-generation system based on solar energy for the production of power, hydrogen, oxygen, heating, cooling and hot water was assessed by Ozturk and Dincer (2013). In addition to this, Al-Ali and Dincer (2014) proposed a multigeneration system and concluded that the energy efficiency of the overall system can be increased from 16.4% to 75% and exergy efficiency can be increased up to 10%, in the event of shifting it from single generation to multigeneration.

Solar energy is the fundamental source of renewable energy among the other sources including; hydropower, waste heat, wind energy and biomass etc. (Joshi et al., 2009). In addition to this, the ample availability of solar energy makes it less costly with zero pollution (Suleman et al., 2014b). Moreover, useful output like power generation is possible through the variety of solar heating systems which include; PTC, solar dishes and solar tower.

In general, the multi-generation system uses one or more energy sources to produce diverse useful outputs. Multi-generation systems not only mitigate environmental impact and cost but also increase efficiency and sustainability. There is a huge connection between the qualities of the available energy for multi-generation with the reference environment. Renewable energy based multigeneration systems produce better efficiency and these are sustainable (Dincer and Zamfirescu, 2012). Al-Sulaiman et al. (2011) performed a study on electrical energy efficiency and found that up to 94% of energy efficiency is possible with tri-generation. Ahmadi et al. (2014) conducted energy and exergy analysis of an ocean thermal energy conversion (OTEC) system for multigeneration and investigated the effects of operating conditions through a parametric study. They used the flat plates as well as PV/T solar collectors to produce fresh water through reverse osmosis (RO) plant, cooling through absorption chiller and hydrogen through proton exchange membrane electrolyzer.

Khalid et al. (2015) developed a solar and biomass-based integrated system to produce multiple outputs and concluded that both efficiencies increase with incorporation of two energy sources. Islam et al. (2015) studied a solar energy based multigeneration system energetically and exergetically, and found an increase of 4.5% in energy efficiency and 5.1% increase in exergy efficiency of PV, through the integration of an exclusive cooling system. Bicer and Dincer (2016) proposed and analyzed a new combined system for the production of hydrogen, power, heat and cooling through solar and geothermal resources.

DiPippo (2015) performed a study based on the conversion efficiency from geothermal to electrical and showed that geothermal power plants can achieve high efficiencies like conventional plants in the presence of good economic conditions and proper incentives. Zarrouk and Purnanto (2015) reviewed the steps to design steam-water separator using Computational Fluid Dynamics (CFD) and showed that the internal diameter of separator body is inversely proportional to the breakdown velocity. Llanos et al. (2015) developed a TOUGH 2 reservoir model for an enhanced geothermal system (EGS), located in Australia by considering four different well