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ScienceDirect

Solar Energy 112 (2015) 290–299

SOLAR ENERGY

www.elsevier.com/locate/solener

Energy and exergy analyses of a solar-biomass integrated cycle for multigeneration

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Received 24 July 2014; received in revised form 21 November 2014; accepted 24 November 2014
Available online 27 December 2014

Communicated by: Associate Editor Michael Epstein

Abstract

A biomass and solar integrated system for multigeneration of useful outputs, in which two renewable energy sources are combined to produce multiple outputs (e.g., power, cooling, hot water, heated air), is developed and presented. Energy and exergy analyses are used to assess the performance of the cycle, and the effects of various system parameters on energy and exergy efficiencies of the overall system and its subsystems are examined. The overall energy and exergy efficiencies of the system are found to be 66.5% and 39.7% respectively. Furthermore, the effect is also investigated of reference-environment temperature on energy and exergy efficiencies for the system, when operated only on biomass and solar energy.

Keywords: Biomass; Efficiency; Exergy; Multigeneration; Solar energy

1. Introduction

Energy usually plays a vital role in the development of a nation. With the gradual depletion of conveniently available fossil fuel reserves, people are seeking other energy sources which are long lasting as well as environmentally benign, like renewable energy. The main renewable energy sources in use nowadays are solar, geothermal, wind, biomass and hydro (Ahmadi et al., 2013). Biomass is mainly derived from living or dead matter present on earth (Cohce et al., 2011). Solar energy can be collected in various ways, e.g., concentrated solar panel and heliostat. In this study, a heliostat field and central receiver are used.

Energy challenges can, to some extent, be overcome by using energy resources more efficiently, and sometimes this can be achieved via trigeneration and multigeneration (Chicco and Mancarella, 2008). Another way of efficiently using energy resources is to integrate them in such a manner that the deficiencies of one energy source are overcome by the other, often leading to the better utilisation of the energy resources.

A number of studies have been reported on trigeneration and multigeneration. Using energy and exergy analyses on a waste heat recovery-based trigeneration system, Khaliq et al. (2009) examined the effect of exhaust inlet gas temperature on the energy and exergy efficiencies and found that energy efficiency increases with increasing exhaust inlet gas temperature while exergy efficiency decreases. Malico et al. (2009) developed a trigeneration system to meet the demands of a hospital for electricity, heating, cooling and hot water, and performed an economic feasibility analysis. An exergy analysis of a Gas

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http://dx.doi.org/10.1016/j.solener.2014.11.027
0038-092X/

Nomenclature

C	compressor
$\dot{E}x$	exergy rate (kW)
ex	specific exergy (kJ/kg)
GT	Gas turbine
h	specific enthalpy (kJ/kg)
HE	heat exchanger
k	specific heat ratio
LHV	lower heating value (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
RT	Rankine turbine
$\dot{Q}$	heat rate (kW)
s	specific entropy (kJ/kg-K)
T	temperature (K)
v	specific volume (m^3/kg)
$\dot{W}$	work rate (kW)

Greek letters

η	energy efficiency
ψ	exergy efficiency
Φ	exergy to energy ratio of the fuel
λ	stoichiometric constant in biomass combustion reaction in Eq. (1) (moles)
α, β, δ, γ	number of atoms of carbon, hydrogen, nitrogen and oxygen in biomass (atoms/molecule)

Subscripts

a	absorber
bio	biomass
c	compressor
ch	chemical
co	condenser
cr	central receiver
d	destruction
e	evaporator
g	generator
gtc	Gas Turbine Cycle
ha	hot Air
hw	hot water
is	isentropic
ov	overall
p	pump
ph	physical
rc	Rankine Cycle
S	source
sol	solar
t	turbine
x, y, z	number of atoms of carbon, hydrogen and oxygen in biomass (atoms/molecule)
0	ambient (or reference environment) condition
1, 2, … 44	state numbers

Turbine for trigeneration by Khaliq (2009) determined that the maximum exergy destruction occurs in the combustion chamber and the steam generator. Al-Sulaiman et al. (2012) performed energy and exergy analyses of a biomass trigeneration system using an organic Rankine Cycle, and found that the maximum exergy efficiency of the organic Rankine Cycle increases from 13% to 28% when they switch from single generation to trigeneration. Ozturk and Dincer (2013) studied a solar-based multigeneration system and found its exergy efficiency to be about 57%. An analysis by Dincer and Zamfirescu (2012) of renewable energy-based multigeneration systems demonstrated that the exergy efficiencies vary from 55% to 65%, depending upon the degree of cogeneration used. Ozturk and Dincer (2013) showed that, through the integration of various systems, multigeneration increases energy and exergy efficiencies. Dincer and Zamfirescu (2011) determined that renewable energy-based multigeneration reduces fuel prices and harmful pollutant emissions, compared to conventional systems. The above studies indicate that multigeneration via the integration of two renewable energy sources can be beneficial.

The specific objectives of this paper are to propose and to assess with energy and exergy analyses a new integrated multigeneration system using biomass and solar energy, including the determination of overall energy and exergy efficiencies of the multigeneration system and its subsystems; and to carry out a parametric study to determine the effects of various parameters on the overall energy and exergy efficiencies of the multigeneration system and its subsystems.

2. System description

The proposed multigeneration system (see Fig. 1) uses two renewable energy sources: solar and biomass. It contains two Rankine and two Gas Turbine Cycles, as well as a absorption cooling cycle. The main outputs of the proposed system are electric power, cooling, hot water and hot air. The most significant part of this system is concentrated solar collector. The solar energy from the sun is collected through a heliostat tower. The heliostat tower reflects the incident solar energy to the central receiver where it absorbs the heat and transfers this heat to the heat transfer fluid. In the concentrated solar collector, the two important aspects for the performance are heliostat aperture area and direct normal irradiation.

2.1. Gas Turbine Cycle 1

Fresh air enters Compressor 1 and the resulting compressed air enters the combustion chamber where it mixes