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Assessment and optimization of a new sextuple energy system incorporated with concentrated photovoltaic thermal - Geothermal using exergy, economic and environmental concepts

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ABSTRACT

This research presents a thermodynamic, economic and environmental impact assessments of a new renewable based sextuple system made up of an organic Rankine cycle, magnetic refrigeration cycle, proton exchange membrane electrolyzer, date dryer unit and concentrated photovoltaic thermal collectors delivering power electricity, cooling and heating effects, hydrogen, oxygen and dried date productions. The impacts of the substantial design parameters on the annual thermal and exergy efficiencies, total product cost and environmental impact rates are evaluated. From parametric analysis, PEM electrolyzer current density affects the product cost rate of the system less than other parameters within 3.05% and turbine inlet pressure yields the reduction in the total product environmental impact rate by about 3.8%. Moreover, an elitist non-dominated sorting genetic algorithm and LINMAP decision maker are employed to identify the final optimum answer of the desired system. From optimization outcomes, the optimum performance of the system shows 18.3% reduction for cost and 24.9% improvement for environmental impact criteria. The annual thermal efficiency is improved about 27.4% and annual exergy efficiency gets 2.12 times. Under the optimum conditions, the isobutane mass flow rate reaches the maximum value of 35 kg/s and net power output increases within 50.25% in relation to the base point.

1. Introduction

Population growth and industry development have led to energy demand rise. The direct consequence of this issue is the air pollution and the significant CO_2 emission from the energy production related to global warming (Lam et al., 2016).

Improving industrial process to increase the energy efficiency, minimizing waste disposals and reducing their impacts through better management, reducing CO_2 emissions by making progress toward lower carbon (Dovì et al., 2009), minimizing emissions and energy wastage by improving industrial processes and integration of renewable energy (Klemeš et al., 2010) are the most effective ways to mitigate the environmental pollution.

In addition, utilizing the advanced MGSs (multi generation systems), a system with more than three different commodities, can play a significant role to save energies and reduce the concerns of air pollution due to their high efficiencies and low greenhouse gas effects. On the other hand, renewable resources due to their sustainable and environmental friendly production processes and products are convenient prime movers for MGSs to meet out energy demand requirements.

Nowadays, proposing and investigating MGSs driven by various renewable energies from the viewpoints of the conventional exergy and exergoeconomic concepts are regarded to be of particular interest for several researchers. Coskun et al., (2012) proposed and thermodynamically analyzed seven various combinations of geothermal based MGSs for practical applications. To examine the performance of desired system, two distinct substantial groups were considered for heating and cooling seasons. Improvement potentials for each system component and the overall system were calculated and compared. Moreover, four thermodynamic criteria; namely, energetic and exergetic renewability rates as well as system energetic and exergetic reinjection rates were studied. They found the overall system energy and exergy efficiencies were increased about 3.40 and 1.12 times for the cooling season and

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Nomenclature

A	area, m^2
$\dot{B}$	environmental impact rate associated with exergy, Pts/s
b	specific environmental impact per unit of exergy, Pts/J
c	cost per unit of exergy, $/J
$\dot{C}$	cost rate associated with an exergy stream, $/s
c_p	specific heat, J/kg K
CPVT	concentrated photovoltaic thermal
C_{wind}	wind speed, m/s
E_{act}	activated energy, kJ/mol
EI	environmental impact
$\dot{E}$	total energy rate, W
ex	specific exergy, J/kg
$\dot{E}x$	total exergy rate, W
F	Faraday constant, C/mol
f	frequency, 1/s
f_c	exergoenvironmental factor, %
f_c	exergoeconomic factor, %
G_B	beam solar radiation, W/m^2
G	Gibbs free energy, kJ
H	total enthalpy, kW
h	specific enthalpy, kJ/kg
J^{ref}	pre-exponential factor, A/m^2
J_o	exchange current density, A/m^2
J	current density, A/m^2
k	thermal conductivity, W/m.K
L	membrane thickness, m
m	mass flow rate, kg/s
$\dot{N}$	molar mass flow rate, mol/s
Nu	Nusselt number
PEM	Proton exchange membrane
Pr	Prandtl number
Q	heat transfer, J
$\dot{Q}$	heat transfer rate, W
r_b	relative environmental impact difference
r_c	relative cost difference
Re	Reynolds number
R_{PEM}	proton exchange membrane resistance, Ω
s	specific entropy, kJ/kg K
T	temperature, K
V_{act}	activation overpotential, V
V_0	reversible potential, V
$V_{act,a}$	anode activation overpotential, V
$V_{act,c}$	cathode activation overpotential, V
V_{ohm}	ohmic overpotential, V
W	work, J
$\dot{W}$	power, W
$\dot{Y}$	component-related environmental impact rate, Pts/s
$\dot{Z}$	cost rate associated with investment expenditures, $/s

Subscripts

amb	ambient
Cond	condenser
conv	convection
coo	cooling
D	destruction
dmg	demagnetization
Evap	evaporator
ex	exergy
f	fluid
F	fuel
g	glass
Geo	geothermal
HEX	heat exchanger
MB	magnetocaloric bed
mg	magnetization
Overall	overall
P	product
pc	potential refrigeration capacity
pl	plate
MAG	magnetization
rad	radiation
th	thermal
tot	total
Tub	turbine
w	water

Greek letters

μ	dynamic viscosity, Pa.s
ΔC	adiabatic temperature in the magnetic material, K
η	efficiency
λ	heat transfer coefficient, $W/m^2.K$
λ_a	water content at the anode-membrane interface, Ω^{-1}
λ_c	water content at the cathode-membrane interface, Ω^{-1}
$\lambda(x)$	water content at location x in the membrane, Ω^{-1}
σ_{PEM}	proton conductivity in PEM, s/m
$\sigma(x)$	local ionic PEM conductivity, s/m
ρ	density, kg/m^3
σ	Stefan Boltzmann constant, $J/s.m^2.K^4$
ε	emissivity

within 4.25 and 1.25 times for the heating season relative to the individual power generating option.

(Ratlamwala et al., 2012) designed and modeled a novel geothermal driven MGS including a double flash power generating, ammonia-water absorption refrigeration cycle, and PEM (proton exchange membrane) electrolyzer to produce cooling, heating, power, hot water and H_2 (hydrogen) using the exergy and exergoeconomic concepts. It was found that the geothermal source temperature, pressure and mass flow rate had negative impacts on cooling effects while the ambient temperature growth led to better exergetic efficiency. Moreover, a 60 K increment in the geothermal temperature increases H_2 produced from 1.85 kg/day to 11.67 kg/day.

(Ozturk and Dincer, 2013) carried out a solar driven MGS involving power, heating, cooling, hot water, hydrogen and oxygen production from the exergy viewpoint. Moreover, the thermodynamic assessment of a solar MGS with the coal gasification, containing power, heating and cooling effects, hydrogen, oxygen and hot water productions was conducted in the next research. In addition, sensitivity analyses were conducted for desired system to evaluate the thermodynamic performance versus the changes of some major design parameters. From the results it was clear that subsystem energy efficiency varied between 19.43 and 46.05% and its exergy efficiency changed between and 14.41–46.14%. MGS had the maximum energy efficiency with value of 54.04% and exergy efficiency with value of 57.72% (Ozturk and Dincer, 2013).