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Thermodynamic assessment of modified Organic Rankine Cycle integrated with parabolic trough collector for hydrogen production

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ABSTRACT

Hydrogen is one of the most clean energy carrier and the best alternative for fossil fuels. In this study, thermodynamic analysis of modified Organic Rankine Cycle (ORC) integrated with Parabolic Trough Collector (PTC) for hydrogen production is investigated. The integrated system investigated in this study consists of a parabolic trough collector, a modified ORC, a single effect absorption cooling system and a PEM electrolyzer. By using parabolic trough collector, solar energy is converted heat energy and then produced heat energy is used in modified ORC to produce electricity. Electricity is then used for hydrogen production. The outputs of this integrated system are electricity, cooling and hydrogen. By performing a parametric study, the effects of design parameters of PTC, modified ORC and PEM electrolyzer on hydrogen production is evaluated. According to the analysis results, solar radiation is one of the most important factor affecting system exergy efficiency and hydrogen production rate. As solar radiation increases from 400 W/m^2 to 1000 W/m^2, exergy efficiency of the system increases 58%–64% and hydrogen production rate increases from 0.1016 kg/h to 0.1028 kg/h.

Introduction

Energy is one of the most critical subjects of present day. Being clean, environmental, safe and cheap are important features of obtaining necessary energy. Beside these features energy consumption should be decreased by informing people about energy saving. Due to increasing life standards energy consumption increases sharply. This situation causes global warming, greenhouse effect, climate change, melting of ice caps, acid precipitation and ozone depletion. Current energy infrastructure is unfortunately not sustainable and it should be renewed in near future. From this perspective, integrated multigeneration systems offer high efficiency, cheap, clean and sustainable solutions for current problem. Integrated multigeneration systems produce several outputs such as power, heating and cooling, hydrogen, some chemicals, hot water etc. Performance parameter is one of the most important factors while implementing a multigeneration system. Besides performance and efficiency, initial capital and operating & maintenance cost should be analyzed in order to conduct an effective and economic multigeneration system [1].

By using thermodynamic assessment method, the general characteristics of an energy production system can be drawn, especially efficiency, environmental impact and economic

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Nomenclature

A_a	Aperture area
A_r	Receiver area
$C_{p,c}$	Specific heat of working fluid
COP	Coefficient of performance
CST	Cold storage tank
D	membrane thickness
$D_{i,r}$	Receiver inside diameter
$D_{o,r}$	Receiver outside diameter
EES	Engineering Equation Solver
$\dot{E}x$	Exergy rate
ex	Specific exergy
F	Faraday constant
F'	Collector efficiency factor
F_R	Heat removal factor
G_t	Total solar radiation
h	Enthalpy
h_{fi}	Heat transfer coefficient
HEX	Heat Exchanger
HST	Hot storage tank
J	Current density
k	Thermal conductivity
L_c	collector length
m	Mass
n_{cp}	Number of collectors in parallels
n_{cs}	Number of collectors in series
ORC	Organic Rankine Cycle
PEM	Proton Exchange Membrane
PTC	Parabolic Trough Collector
R	Resistance
RT	Rankine turbine
Q	Heat
S	Absorbed solar radiation
SEACS	Single Effect Absorption Cooling System
T_o	Ambient temperature
T_{ri}	receiver inlet temperature
U_L	Heat loss coefficient
V	Potential
$\dot{W}$	Work rate
α_r	absorptivity of receiver
γ	correction factor for diffuse radiation
ΔG	Gibb's free energy change
Δt_h	total time of changing period
ΔT	change of temperature
η	Energy efficiency
Ψ	Exergy efficiency
λ	Water contents
τ_{cover}	transmissivity of the cover glazing
τ_{PTC}	effective transmissivity of the parabolic trough collector

charge of the system. Energy analysis cannot emphasize the losses in the process, so it should be supported by exergy analysis based on the second law of thermodynamics to highlight where and how irreversibilities occur. Rosen and Scott [2] proposed a system producing methanol by using natural gas sources. They have investigated the system in terms of energetic and exergetic viewpoint. According to the results, efficiencies of methanol generation system are quite close to each other with energy efficiency 39% and exergy efficiency 41%.

Gao et al. [3] have proposed a poly-generation system using coal as a main source producing power and chemicals. They have compared this poly-generation system with an individual energy production system in terms of exergy efficiency. As a result, poly-generation system has higher efficiency than the individual one. By integrating chemical production, system has saved 3.9% energy.

In another study, Carvalho et al. [4] have tried to lower total annual cost and harmfull emissions of a hospital. To achieve this, a tri-generation system has been proposed. To meet optimum criteria, a model has been selected with lower cost and environmental friendly option. The needs of the hospital such as power, cooling and heating have been determined. As a result, they have found that there is an inverse proportion between cost and emissions.

Solar energy is one of the most suitable energy source type for local needs and it is environmental benign. Because of that, parabolic trough collector is used in this study to meet the thermal energy need of organic Rankine cycle. Parabolic trough collectors is the most used collector technology in the world, as seen from Fig. 1 [5].

Hydrogen production via solar energy is getting popular because hydrogen is the most promising energy carrier for near future. Omar and Altinişik [6] have published a study which comprises of a simulation of hydrogen production system with hybrid solar collector. They have found the most suitable city among three by varying pressure and temperature with constant temperature and pressure, respectively.

Energetic and exergetic performance with parametric analyses is performed in another study conducted by Joshi et al. [7]. According to that study, exergy efficiency of system has the peak value at 400 °C of collector surface temperature.

Khanmojammadi et al. [8] proposed an integrated solar based system producing hydrogen and cooling. They have performed an optimization study based on the outlet temperature of generator, inlet temperature to ORC turbine, solar irradiation intensity, collector mass flow rate and flat plate collector area. Resultingly, they have reported that the exergy efficiency of the system can be improved from 1.72% to 3.2%.

In order to increase the performance of water electrolysis, some new methods are being tried. One of them is to use alkaline water electrolysis method by putting 30% potassium hydroxide in water. Bhattacharyya et al. [9] performed this method to produce hydrogen from alkaline water electrolysis and they have conducted thermodynamic analysis to the system. As a result with some varying parameters, energy efficiency of conversion changes between 14 and 16% and exergy efficiency ranges from 8% to 16%.

Another method for producing hydrogen is methanol reforming. Real et al. [10] have conducted a solar powered methanol reforming system in order to produce hydrogen. The system by means of solar collector having up to 260 °C temperature, maximum hydrogen production is achieved with 6.62 L_{STP} min−1 m−2. According to results, efficiency of hydrogen production is about 78% and total energetic efficiency of the system is almost 43%.

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