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Thermodynamic performance assessment of ocean thermal energy conversion based hydrogen production and liquefaction process

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ABSTRACT

In the proposed study, the thermodynamic performance assessment of ocean thermal energy conversion (OTEC) based hydrogen generation and liquefaction system are evaluated. In this context, the energetic and exergetic analyses of integrated system are conducted for multigeneration. This integrated process is consisted of the heat exchangers, turbine, condenser, pumps, solar collector system, hot storage tank, cold storage tank and proton exchange membrane (PEM) electrolyzer. In addition to that, the impacts of different design indicators and reference ambient parameters on the exergetic performance and exergy destruction rate of OTEC based hydrogen production system are analyzed. The energetic and exergetic efficiencies of integrated system are founded as 43.49% and 36.49%, respectively.

Introduction

Energy production and consumption are accepted as exceedingly critical issue in last years because they are linked to such as economic, social, environmental conditions of countries. While energy demand increases together with population growth and demands for better living standards, climate change raises deeper concerns related to fossil-fuel based energy use. Because as a large proportion of energy production is still derived from fossil fuels, environmental problems continue to increase such as global warming, resource depletion, and environmental damage etc. In addition, in the coming years, the use of alternative fuels will be inevitable because of the limited fossil fuels. In this context, the free-carbon sources (hydrogen) and renewable energy sources will become promising for energy consumption sectors [1].

If the hydrogen is obtained from renewable and sustainable energy resources, it is expected to play an important role as a power carrier. The use of hydrogen in the gas or liquid phase has many advantages as a fuel [2]. The generated hydrogen in liquid or gaseous forms can be used in all sorts of the energy process, like thermal energy sector, transportation, etc. When hydrogen burns, it does not give pollutant wastes to the environment. Meanwhile, the global rate of hydrogen use is increasing by nearly 3–4% annually, due to the rising energy

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Nomenclature

A	Surface area (m^2)
Con	Condenser
CST	Cold Storage Tank
ex	Specific exergy (kJ/kg)
FPSC	Flat-plate solar collector
h	Specific enthalpy (kJ/kg)
Hex	heat exchanger
HST	Hot Storage Tank
I	Irradiance (W/m^2)
OTEC	Ocean thermal energy conversion
P	pump
PEM	Proton exchange membrane
s	Specific entropy (kJ/kg K)
T	Temperature (°C or K)
$\dot{E}_D$	Exergy destruction rate (kW)
$\dot{E}_x$	Exergy flow rate (kW)
$\dot{Q}$	Heat transfer rate (kW)
$\dot{m}$	Mass flow rate (kg/s)
Greek Letters	
η	Energy efficiency
ψ	Exergy efficiency
Acronyms	
e	exit
in	input

demand [3]. Therefore, it is hoped that hydrogen will work on using it as a fuel in next years.

Currently, hydrogen storage is very important issue as well as production. The gaseous hydrogen more storage volume than natural gas, petrol and gasoline for amount unit energy. Therefore, the storage processes of hydrogen as liquid form are essential mission in order to use as an energy carrier in future years. At this point, there are a need for studies on the hydrogen production and storage.

A series of papers have been proposed on trigeneration and multigeneration system for hydrogen production [4–7]. Ngoh et al. [4], have proposed a hybrid solar photovoltaic thermal energy based integrated hydrogen production system. In their theoretical study, hydrogen production rate of per second and per day under the optimum situation are 0.064 kg/s and 1843.2 kg/day. The exergy efficiency of system components was also investigated.

Ozturk and Dincer [5], have investigated a thermodynamic performance analyses of solar based multigeneration system for hydrogen production. The overall exergy efficiency of solar based multigeneration system was calculates as 57.35%. They argued that the highest exergy destruction rate seen in parabolic dish collector because of the high temperature difference with receiver and working fluid.

Pregger et al. [6] have presented a possibility of solar thermal hydrogen production systems. Also, it can be said that this work presents a solar thermal hydrogen production system in terms of economic and technologic potentials and their possible role of the future need for hydrogen. This work is mainly emphases on thermochemical cycles, solar methane reforming, water electrolysis with high temperature and solar methane cracking. Also, they have discussed the future and current status of these processes for hydrogen production.

Balta et al. [7], have examined an energy and exergy efficiency of integrated hydrogen production system with high temperature steam electrolysis. In this study, they have proposed thermodynamic performance assessment of solar based high temperature steam electrolysis with hydrogen production system in detailed. According to the results of their study, the overall energy and exergy efficiencies was calculated as 24.79% and 22.36% respectively, and the hydrogen production rate is 0.057 kg/s.

Asadnia and Mehrpooya [8] have investigated a novel large-scale plant for hydrogen liquefaction. They have analyzed 100 tons per day liquid hydrogen production plant mixed refrigerant system. In the pre-cooling section of the process, a new mixed refrigerant (MR) cooling circuit is combined and gaseous hydrogen feed from 25 °C to the temperature −198.2 °C. Also, specific energy consumption of this process is 7.69 kWh/kg_{LH2}, while the energy consumption is 2.89 kWh/kg_{LH2} under the ideal conditions.

Salkuyeh et al. [9] have examined a techno-economic analyses and life cycle assessment of four hydrogen generation system based on natural gas as feedstock. They have evaluated and compared to auto thermal, stem methane reforms and two innovative technologies which are synthesis gas chemical looping (SCL) and chemical looping reforming (CLR) system for hydrogen production. From their study understood that the highest thermal efficiency is obtained from CLR option as 84%. Kanoglu et al. [10], have studied a geothermal based absorption precooling of hydrogen and using the Claude process for hydrogen liquefaction. The coefficient of performance (COP) of ammonia-water refrigeration system and exergy efficiency of integrated system has calculated as 0.162 and 67.9%, respectively. Ozcan and Dincer [11], have displayed a thermodynamic assessment of hydrogen production and liquefaction system using by nuclear based Mg–Cl cycle. In their paper, the energy and exergy efficiency of whole process have been calculated as 18.6% and 32.35%, respectively. Sadaghiani and Mehrpooya [12], have presented a novel hydrogen liquefaction process. They have used two separated refrigeration systems with different mixed refrigerants for hydrogen liquefaction. According to their study results, the exergetic performance of first and second refrigeration systems are founded as 67.53% and 52.24%, respectively. The geothermal based hydrogen production and liquefaction in terms of economics have been investigated by Yilmaz et al. [13]. They have examined the geothermal assisted seven processes for hydrogen generation and liquefaction. In their study, a precooled Linde-Hampson method is used for hydrogen liquefaction. From their work, it can be said that the cost of hydrogen production and liquefaction varieties from 0.979 \$/kg H_2 to 2.615 \$/kg H_2. Also, they have put forward the cost of hydrogen production and liquefaction decreases with increase in geothermal water temperature.

Ratlamwala et al. [14], have investigated a novel absorption system through geothermal power for hydrogen liquefaction, power, heating and cooling. They have presented the variation of energetic and exergetic efficiencies of overall system according to various system design parameters such as