HYDROGEN, FUEL CELL & ENERGY STORAGE

Analysis and performance evaluation of a multigeneration system applying PV/T and PTC solar collectors from hydrogen and freshwater production point of view

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Abstract

This study aimed to analyze a novel multigeneration system which uses the PTC and the PVT solar collectors as the energy sources. The main productions of this system is power, hot water, cooling, hydrogen and freshwater. The introduced system included the Rankine cycle, the double effect organic refrigeration system, the PEM electrolyzer and the RO desalination unit. The EES software was used to analyse energy, exergy, thermoeconomics and a range of parameters. As the results show, the highest amount of exergy destruction is associated with the PTC collector, ORC cycle and PEM electrolyzer, according to the exergy destruction analysis of the main cycles. The rise in the collector area, solar radiation and ORC turbine inlet temperature leads to higher levels of hydrogen and freshwater production. Moreover, investigating different working fluids in the ORC cycle proves that R141b shows the best performance from point of view of hydrogen and freshwater production rates. Furthermore, 33.49% and 13.31% are found for the energetic and the exergetic performance of the system, respectively.

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1 Introduction

The economic development of nations around the world has been dependent on finite fossil fuels in recent decades. The need for a long term perspective and the creation of plans to deal with energy issues had not been feltuntil the 1973 oil crisis. The pressure on energy consumption policies in countries to change has intensified as a result of the oil crisis and environmental impacts such as weather change, global warming or damage to the ozone layer caused by greenhouse gases [1]. For the development of human life, access to energy is an essential parameter. To overcome the current global energy challenges, two main technological barriers remain: efficiency of energy technologies and use of renewables. Significant growth in energy consumption is a result of the economic development that has been taking place over the last century in many parts of the world. Unfortunately, fossil fuel remains a primary energy source and hence, one of the most important reasons of global warming. The rise in CO_2 exportations is continuing as a result of oil, gas and coal consumption. Industrial activities have increased the volume of waste heat, driven by an increasing use of fossil fuels. A number of studies indicate that 25 to 50% of input energy is used for industry while the remaining volume is burned off as waste heat [2–4]. Some heat recovery facilities and technologies may be put in place to limit the amount of this waste heat through upgrading equipment efficiency and best energy use. However, it is practically not possible to prevent industrial activities from leading to loss of heat. In recent years, research and business interests have focused on developing multigeneration systems that allow for immediate production of electricity or heat or cold within the context of reduced energy consumption, thereby reducing greenhouse gas emissions. This type of system uses the waste heat from power generation systems for heating and cooling purposes so that its overall efficiency can be increased.

Many studies have been carried out in the past years on multigenerator cycles using solar energy, organic rankine cycle (ORC) and absorption systems. In order to meet the heating, cooling and electricity requirements of the hospital, Aghaziarti and Aghdam [5] have presented an organic Rankine cycle system combined with a refrigeration cascade system. Energy, exergy and exergyeconomic analysis has been carried out on this system. The energy and exergy efficiency of the system shall be measured as 39.89% and 70.8%, respectively. It is clear from the value of exergy destruction in the components of the system that the main source of irreversibility is the solar collector.

Hou et al. [6] investigated a solar based organic Rankine cycle with parabolic collectors and thermal storage devices to collect solar radiation for continuous operation of the electrical system. The outcomes prove that system performance can be improved by rising the inlet pressure of turbines, mass flow of thermal oil from steam engines and parabolic filters as well as lower temperatures in cooling water. Optimisation results show that, under the conditions described above, an optimal solution is obtained with a net power of 143.02 kW and an average daily exergy efficiency of 75.9%.

Cao et al. [7] presented a new arrangement process of a combined power, heating and cooling generation system using parabolic trough collectors (PTC), which results in higher output. Solar subsystem, organic Rankine cycle for power generation, heat exchanger and a Single Effect Absorption chiller use the waste heat of the organic Rankine cycle to produce heating and air conditioning. Adding an organic Rankine cycle with a regenerator, three heat exchangers in the heating process and a double absorptioneffect chiller have changed the primary system. Compared to the base system, for the chenged system, the power generation is improved by 10.4%, 18.4%, and 3% in the aforesaid operating modes, respectively. In addition, the electric efficiency of an altered system is 1.4%, 0.9% and 0.3% higher for these modes compared to the base value.

A simulation study focused on the thermodynamic analysis of the solar trigeneration system for heating, cooling and power generation has been presented by Bellos and Tzivanidis [8]. The organic Rankine cycle and the absorption heat pump are fed by linear parabolic collectors in this system. A study has been carried out to specify the influence of different parameters on energy efficiency, system exergy performance, electricity production, heating and refrigeration during a low payback period for investments. Based on the results, energy efficiency of this system is 40.7% and exergy has been 12.7%. The financial analysis of the investment has shown that the plan with a simple repayment period of 1.8 years is feasible in the nominal state and can be reduced to 8.7 years with an optimisation method.

A new hybrid multigeneration system consisting of parabolic solar collectors and photovoltaics thermal collector units has been proposed by Raja and Huang [9]. A parabolic solar collector, organic Rankine cycle and absorption refrigeration system for the generation of power, hydrogen production and cooling is part of the proposed system. In accordance with the results, a total energy efficiency and electrical exergy of system 477 K, 90.12% and 72.54% were calculated in terms of outlet temperature at sun's fluid stream. Dynamic solar combined cooling, heating, power and water production systems were studied by Pourmoghadam and Kasaeian [10].

In addition, a phase change material energy storage device has been applied to store and reuse electricity when the sun's radiation modes are lower or not there at all. The amounts of levelized cost of water (LCOW), levelized cost of energy (LCOE), levelized cost of cooling (LCOC), and levelized cost of heating (LCOH) for the base case are 2.984 $\$/m^3$, 0.121 \$/kWh, 0.064 \$/kWh, and 0.019 \$/kWh, respectively. Moreover, the payback period is set at six years in respect of the base case. Shabani and Babaelahi [11] have proposed a new solar based hybrid system for power generation, desalination, hydrogen production and refrigeration. The system is a combination of Kalina cycle, parabolic trough solar collectors, organic Rankine cycle, polymer electrolyte membrane electrolyzer, multi-effect distillation, ejector cooling and Brayton cycle. The system output is 32.269 MW net power and the coefficienct of performance (COP) of ejector 0.3193. For both applications, the total efficiency of energy and exergy is 38.45% and 35.64%, respectively.

Mahmoudi et al. [12] studied a novel multigeneration system introduced using nanofluid in a solar system. The proposed system includes a quadruple effect absorption refrigeration cycle, a thermoelectric generator, a PEM electrolyzer, a vapor generator, and a domestic water heater. The results showed that the hydrogen production rate decreases by increasing the volume concentration of the nanoparticles, the solar radiation, and the figure of merit index. Rahimi et al. [13] investigated a system including a PV unit, a proton exchange membrane electrolyzer, a proton exchange membrane fuel cell, and a battery storage unit. Additionally, an ORC system was integrated to efficiently capture and utilize waste heat generated by the PEMFC. The results indicate that an optimal ORC turbine inlet pressure of approximately 600 kPa maximizes overall exergy and energy efficiencies by 53.2% and 50.9%, respectively.

By reviewing previous studies on multigeneration cycles, it was found that many studies have been done on solar energy-based systems. But in most of these articles, a defined type of solar collector has been used. Therefore, in this study, the thermodynamic and thermoeconomic investigation of a multigeneration system reinforced with a thermoelectric generator for the purposes of electricity production, cooling, heating, hydrogen and desalination based on PV/T and PTC solar collectors has been discussed. The innovation of this research is the simultaneous use of two different solar collectors for a multigeneration cycle. Also, a thermoelectric generator unit has been used in this system to improve the power production of the system.

2 System description

In this research, a multigeneration system including two solar collectors consisting of a parabolic trough solar collector (PTC) and Photovoltaic-thermal solar collector (PV/T) is applied as the primary drivers. The subsystems used in this multigeneration system are the ORC cycle to produce power, Double-effect absorption refrigeration cycle (DEARC) to produce cooling, Domestic water heater (DWH) to produce hot water, Proton exchange membrane (PEM) electrolyzer to produce hydrogen and Reverse Osmosis (RO) water desalination unit to generate fresh water. It should be noted that the PTC solar collector is the energy source of the ORC cycle and the PV/T solar collector is the energy source of the double-effect absorption refrigeration cycle. The schematic of the studied solar-based multigeneration system is displayed in Figure 1.

Two solar collectors, PTC and PVT, collect the sun's power in this system. In the first part of the proposed system, the PTC collector is applied to absorb the solar energy. The operating fluid applied for the collector is Therminol_VP1. If there is insufficient sunlight, the working fluid shall be moved to a cold storage tank at point 1 for use when it absorbs heat from an PTC solar collector and turns into warm working fluid. After passing through the storage tank, at point 2 it will pass through an ORC evaporator of organic Rankine cycle to heat its working fluids. The working fluid shall be applied for heating water at point 3 following the passage of the evaporator in order to take as much energy as possible from it. Then, at point 4, it enters the storage tank and finally, at point 5, it is pumped towards the collector. In the organic Rankine cycle, a pump pumps an output working fluid from heat exchanger which is a saturated liquid into the inlet pressure of the turbine and then passes through ORC evaporators to absorb energy obtained by solar collectors. In order to make the mechanical work, this fluid is then expanded into a spinning machine. An electrical generator connected to the engine is driven by mechanical energy generated from the turbines and generates electricity. The TEG unit is then supplied with the output fluid from the engine. In order to obtain additional power, a TEG unit is used instead of an ORC condenser. The photovoltaic thermal (PV/T) system is applied to produce the needed power of the system and cooling in double-effect absorption refrigeration system. In order to produce freshwater and hydrogen, the PVT unit's electricity is added to the energy produced by an ORC turbine and TEG generator for use in a RO or PEM electrolyzer. Double-effect absorption chillers includes three pressure levels: high, medium and low. The high-pressure desorber operates under high pressure and temperature while the low desorber and the condenser work at medium pressure, the evaporator and absorber work at low pressure.

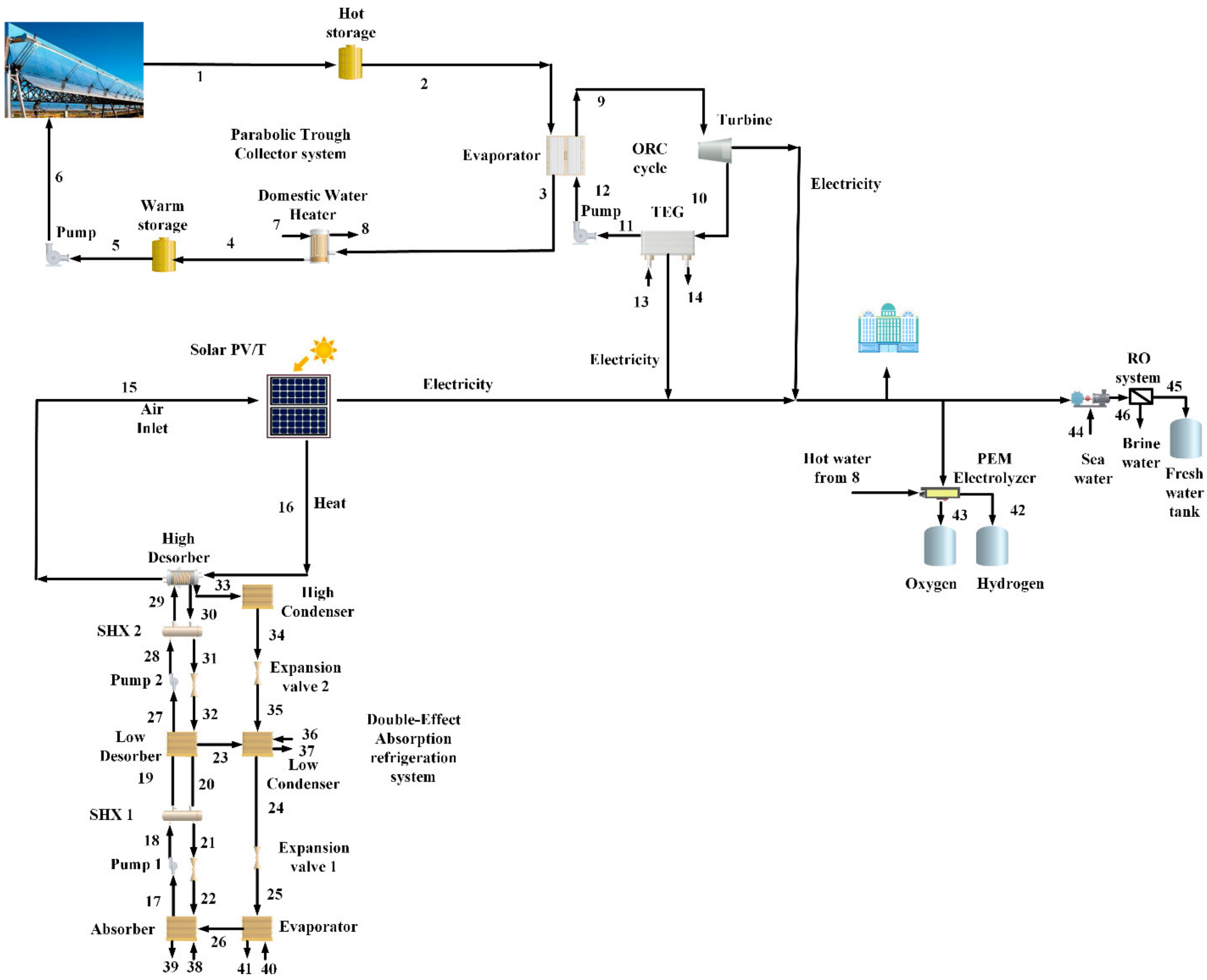

Fig. 1. Schematic of the solar-based multigeneration system.

The strong solution from the absorber must enter the high desorber by means of pumps and heat exchangers within this system. The strong solution is broken down and the resulting water vapour enters the high condenser and is directed to the low condenser after passing the expansion valve after it has been heated in the high desorber. After passing through a solution heat exchanger and an expansion valve, the solution from the high desorber will also enter the low desorber. When it receives heat, it loses some of its water in the form of steam and becomes a more diluted solution and returns to the absorber after passing the solution heat exchanger and the expansion valve. In order to complete the cooling cycle, the cooled refrigerant in the low condenser is returned to the evaporator by means of an expansion valve.

3 System modeling

The basic equations of thermodynamics, which include mass and energy balance relations, are written for each component of the system, and all the analyzes are simulated by Engineering Equation Solver [14] (EES) software. The general assumptions are stated below:

i. The system works in steady state.

ii. No pressure drop is assumed in evaporator, condenser and all heat exchangers.
iii. The fluid at the exit of the condenser is saturated liquid.
iv. Pump and turbine efficiency is isentropic.
v. All studied components of the system are defined as control volume.
vi. Solar radiation is assumed to be uniform and in steady state.

3.1 Mathematical modeling

The basic equations applied for modeling this system are [15–17]:

$$\sum \dot{m}_{\text{in}} - \sum \dot{m}_{\text{out}} = \frac{m_{cv}}{d_t} \tag{1}$$

$$\dot{Q} - \dot{W} = \sum_{\text{out}} (mh) - \sum_{\text{in}} (mh) \tag{2}$$

$$\dot{\text{E}}\text{x}_Q + \sum_{\text{in}} \dot{m}_{\text{in}}\, \text{ex}_{\text{in}} = \sum_{\text{out}} \dot{m}_{\text{out}}\, \text{ex}_{\text{out}} \tag{3}$$

3.2 Parabolic trough collector

The useful power acquired from the collector is equal to [18]:

$$Q_u = n_{\text{cp}} n_{\text{cs}} F_R A_{\text{ap}} \Big[S - \frac{A_r}{A_{\text{ap}}} U_L (T_{r,i} - T_0) \Big] . \tag{4}$$

The collector aperture area is described as follows:

$$A_{\text{ap}} = (w - D) L . \tag{5}$$

The radiation absorbed by the receiver is equal to

$$S = G_b \eta_r . \tag{6}$$

Heat removal factor is obtained from

$$F_R = \frac{\dot{m} c_{p,c}}{A_r U_L} \Big[1 - \exp\Big(- \frac{A_r U_L F_l}{\dot{m} c_{p,c}} \Big) \Big] . \tag{7}$$

F_l is the collector efficiency factor which is described as follows:

$$F_l = \frac{\dfrac{1}{U_L}}{\dfrac{1}{U_L} + \dfrac{D_{r,0}}{h_{fi}} + (\dfrac{D_{r,0}}{2k} \ln \dfrac{D_{r,0}}{D_{r,i}})} . \tag{8}$$

The input heat to the linear parabolic solar collector is expressed as follows:

$$Q_s = A_{\text{ap}} G_b . \tag{9}$$

The energy efficiency of the solar collector is determined from the equations proposed by Duffy and Beckman [19] as follows:

$$\eta_{\text{th,PTC}} = \frac{Q_u}{Q_s} . \tag{10}$$

The following equation is used to compute the exergy of the solar collector:

$$\dot{\text{E}}\text{x}_s = A_{ap} G_b \left[1 + \frac{1}{3} \left(\frac{T_0}{T_s} \right)^4 - \frac{4}{3} \left(\frac{T_0}{T_s} \right) \right] . \tag{11}$$

3.3 Photovotaic thermal collector

The power produced by the PV module shall be calculated as follows [20]:

$$P_{\text{PVT}} = \eta_c \dot{I} \beta_c \tau_g A . \tag{12}$$

As a result, the rate of effective heat output from PVT's air collectors is shown below.

$$\dot{Q}_{\text{PVT,solar}} = \frac{\dot{m}_{\text{air}} \text{Cp}_{\text{air}}}{U_L} \Big[h_{p2z} Z \dot{I} - U_L (T_{\text{air,in}} - T_0) \Big] \times \Big[1 - \exp\Big(- \frac{b U_L L}{\dot{m}_{\text{air}} \text{Cp}_{\text{air}}} \Big) \Big] , \tag{13}$$

$$A_{\text{PVT}} = \alpha_b \tau_g^2 (1 - \beta_c) + h_{p1G} \tau_g \beta_c (\alpha_c - \beta_c) . \tag{14}$$

The energy balance for the panel can be calculated by means of the air exit temperature of the PVT panel as follows:

$$T_{\text{air,out}} = \left[T_0 + \frac{h_{p2z} Z \dot{I}}{U_L} \right] \left[1 - \frac{1 - \exp\Big(\dfrac{- b U_L L}{\dot{m}_{\text{air}} \text{Cp}_{\text{air}}} \Big)}{\dfrac{b U_L L}{\dot{m}_{\text{air}} \text{Cp}_{\text{air}}}} \right] + T_{\text{air,in}} \left[1 - \frac{1 - \exp\Big(\dfrac{- b U_L L}{\dot{m}_{\text{air}} \text{Cp}_{\text{air}}} \Big)}{\dfrac{b U_L L}{\dot{m}_{\text{air}} \text{Cp}_{\text{air}}}} \right] . \tag{15}$$

Equations of exergy destruction rate and cost balance for each component of the studied system is presented in Table 1.

4 Results and discussion

In order to model a multi-generation system, certain parameters have been chosen as input data for simulation. Table 2 shows the input parameters of the system model. To carry out other calculations, these parameters must be set at the beginning. Table 3 shows the overall results after simulation of a system using EES software.

The exergy destruction rate in the important parts of the system analysed is shown in Figure 2. As can be seen in the chart, there is a higher rate of exergy loss at PTC collectors and organic Rankine cycles. In the solar system, much of the exergy of solar radiation is transferred to the environment as thermal waste from solar collectors. The high temperature difference between the liquid coming in and the surface temperatures of the panels is a reason for their high destruction rate in Solar System.

The influence of increasing the PTC solar collector area on the amount of hydrogen and freshwater rate production is depicted in Figure 3. The mass flow rate in the solar cycle is increased by increasing the area of the solar collectors. The increase of the solar system's mass flow rate leads to a higher ORC cycle, resulting in more power being generated within the system. The more power produced in the multigeneration system, the more hydrogen and freshwater is generated in the PEM electrolyzer and the RO unit.

Figure 4 shows the influence of variations in solar radiation strength on hydrogen and freshwater production from the proposed system. As it can be seen from the graphs, by increasing the solar radiation intensity from 500 W/m^2 to 1000 W/m^2, the amount of hydrogen produced by the PEM electrolyzer rises from 215.4 kg/day to 698.8 kg/day and the amount of freshwater generated by the RO desalination unit changes from 2.871 kg/s to 5.175 kg/s. As solar radiation goes up, the amount of energy produced by the system is increased and that leads to an increase in output from PEM and RO units.

Table 1. Equations of exergy destruction rate and cost balance for each component of the proposed system.

Component	Energy balance equations	Exergy destruction rate equations
PTC collector	$\dot{m}_6 h_6 + \dot{Q}_u = \dot{m}_1 h_1$	$\dot{Ex}_{D,\mathrm{PTC}} = \dot{Ex}_{\mathrm{sun}} + \dot{Ex}_6 - \dot{Ex}_1$
PV/T collector	$\dot{m}_{15} h_{15} + \dot{Q}_u = \dot{m}_1 h_1$	$\dot{Ex}_{D,\mathrm{PVT}} = \dot{Ex}_{\mathrm{sun}} + \dot{Ex}_{15} - \dot{Ex}_{16}$
Hot storage	$\dot{Q}_{\mathrm{hs}} = U(T_1 - T_0)$	$\dot{Ex}_{d,\mathrm{hs}} = \dot{Ex}_1 - \dot{Ex}_2 - \dot{Ex}_Q$
DWH	$\dot{Q}_{\mathrm{DWH}} = \dot{m}_3(h_3 - h_4) = \dot{m}_7(h_8 - h_7)$	$\dot{Ex}_{\mathrm{DWH}} = \dot{Ex}_3 + \dot{Ex}_7 - \dot{Ex}_4 - \dot{Ex}_8$
Warm storage	$\dot{Q}_{\mathrm{ws}} = U(T_4 - T_0)$	$\dot{Ex}_{d,\mathrm{ws}} = \dot{Ex}_4 - \dot{Ex}_5 - \dot{Ex}_{Q,\mathrm{ws}}$
ORC evaporator	$\dot{Q}_{\mathrm{eva,ORC}} = \dot{m}_2(h_2 - h_3) = \dot{m}_9(h_9 - h_{12})$	$\dot{Ex}_{D,\mathrm{eva,ORC}} = \dot{Ex}_2 + \dot{Ex}_9 - \dot{Ex}_3 - \dot{Ex}_{12}$
ORC turbine	$\dot{W}_{t,\mathrm{ORC}} = \dot{m}_9(h_9 - h_{10})$	$\dot{Ex}_{D,t,\mathrm{ORC}} = \dot{Ex}_9 - \dot{W}_{t,\mathrm{ORC}} - \dot{Ex}_{10}$
ORC TEG	$\dot{Q}_{\mathrm{TEG,ORC}} = \dot{m}_{10}(h_{10} - h_{11}) = \dot{m}_{13}(h_{14} - h_{13})$	$\dot{Ex}_{D,\ \mathrm{TEG,ORC}} = \dot{Ex}_{10} + \dot{Ex}_{13} - \dot{Ex}_{11} - \dot{Ex}_{14}$
ORC pump	$\dot{W}_{p,\mathrm{ORC}} = \dot{m}_{11}(h_{12} - h_{11})$	$\dot{Ex}_{D,p,\mathrm{ORC}} = \dot{W}_{p,\mathrm{ORC}} - \dot{Ex}_{11} + \dot{Ex}_{12}$
DEARC-High desorber	$\dot{Q}_{\mathrm{Hdes,DEARC}} = \dot{m}_{15}(h_{16} - h_{15})$	$\dot{Ex}_{d,\mathrm{DEARC,Hdes}} =$ $\dot{Ex}_{16} + \dot{Ex}_{29} - \dot{Ex}_{15} - \dot{Ex}_{30} - \dot{Ex}_{33}$
DEARC-High condenser	$\dot{Q}_{\mathrm{Hcond,DEARC}} = \dot{m}_{33}(h_{33} - h_{34})$	$\dot{Ex}_{d,\mathrm{Hcond,DEARC}} = \dot{Ex}_{33} - \dot{Ex}_{34}$
DEARC-Solution heat exchanger 1	$\dot{Q}_{\mathrm{SHX,1,DEARC}} = \dot{m}_{20}(h_{20} - h_{21})$ $= \dot{m}_{18}(h_{19} - h_{18})$	$\dot{Ex}_{d,\mathrm{SHX,1,DEARC}} =$ $\dot{Ex}_{18} + \dot{Ex}_{20} - \dot{Ex}_{19} - \dot{Ex}_{21}$
DEARC-Solution heat exchanger 2	$\dot{Q}_{\mathrm{SHX,2,DEARC}} = \dot{m}_{30}(h_{30} - h_{31})$ $= \dot{m}_{28}(h_{29} - h_{28})$	$\dot{Ex}_{d,\mathrm{SHX,2,DEARC}} =$ $\dot{Ex}_{28} + \dot{Ex}_{30} - \dot{Ex}_{29} - \dot{Ex}_{31}$
DEARC-Low condenser	$\dot{Q}_{\mathrm{Lcond,DEARC}} = \dot{m}_{23} h_{23} + \dot{m}_{35} h_{35} - \dot{m}_{24} h_{24}$ $= \dot{m}_{36}(h_{37} - h_{36})$	$\dot{Ex}_{d,\mathrm{Lcond,DEARC}} =$ $\dot{Ex}_{23} + \dot{Ex}_{35} + \dot{Ex}_{36} - \dot{Ex}_{24} - \dot{Ex}_{37}$
DEARC-Low desorber	$\dot{Q}_{\mathrm{Ldes,DEARC}} = \dot{m}_{32}(h_{32} - h_{20})$ $= \dot{m}_{19}(h_{27} - h_{19})$	$\dot{Ex}_{d,\mathrm{Ldes,DEARC}} =$ $\dot{Ex}_{20} + \dot{Ex}_{23} + \dot{Ex}_{27} - \dot{Ex}_{32} - \dot{Ex}_{19}$
DEARC-Evaporator	$\dot{Q}_{\mathrm{eva,DEARC}} = \dot{m}_{26}(h_{26} - h_{25}) = \dot{m}_{40}(h_{41} - h_{40})$	$\dot{Ex}_{d,\mathrm{eva,DEARC}} = \dot{Ex}_{25} + \dot{Ex}_{40} - \dot{Ex}_{26} - \dot{Ex}_{41}$
DEARC-Absorber	$\dot{Q}_{\mathrm{abs,DEARC}} = \dot{m}_{26} h_{26} + \dot{m}_{22} h_{22} - \dot{m}_{17} h_{17}$ $= \dot{m}_{38}(h_{39} - h_{38})$	$\dot{Ex}_{d,\mathrm{abs,DEARC}} =$ $\dot{Ex}_{26} + \dot{Ex}_{22} + \dot{Ex}_{38} - \dot{Ex}_{17} - \dot{Ex}_{39}$
DEARC-Pump 1	$\dot{W}_{p1,\mathrm{DEARC}} = \dot{m}_{17}(h_{18} - h_{17})$	$\dot{Ex}_{d,p1,\mathrm{DEARC}} = \dot{W}_{p1,\mathrm{DEARC}} + \dot{Ex}_{17} - \dot{Ex}_{18}$
DEARC-Pump 2	$\dot{W}_{p2,\mathrm{DEARC}} = \dot{m}_{27}(h_{28} - h_{27})$	$\dot{Ex}_{d,p2,\mathrm{DEARC}} = \dot{W}_{p2,\mathrm{DEARC}} + \dot{Ex}_{27} - \dot{Ex}_{28}$
PEM	$\dot{W}_{\mathrm{PEM}} = \dot{m}_8 h_8 - \dot{m}_{42} h_{42} - \dot{m}_{43} h_{43}$	$\dot{Ex}_{D,\mathrm{PEM}} = \dot{Ex}_8 + \dot{W}_{\mathrm{PEM}} - \dot{Ex}_{42} - \dot{Ex}_{43}$
RO	$\dot{W}_{\mathrm{RO}} = \dot{m}_{44} h_{44} - \dot{m}_{45} h_{45} - \dot{m}_{46} h_{46}$	$\dot{Ex}_{D,\mathrm{RO}} = \dot{Ex}_{44} - \dot{Ex}_{45} - \dot{Ex}_{46}$

Table 2. Input parameters for the modeling of the present study [21–26].

Parameters	Unit	Value
Collector width	m	5.76
Collector length	m	99
Receiver outside diameter	m	0.07
Recovery ratio	-	0.3
Number of elements	-	7
Number of pressure vessels	-	42
Seawater salinity	m/kg	43
Turbine inlet temperature	°C	150
Turbine pressure ratio	-	5
Pump inlet temperature	°C	80
P_{H_2}, P_{O_2}	atm	1
T_{PEM}	°C	80
$E_{act,a}$	kJ/mol	76
$E_{act,c}$	kJ/mol	18
λ_a	-	14
λ_c	-	10
D	mm	50
J_a^{ref}	A/m^2	1.7×10^5
J_c^{ref}	A/m^2	4.6×10^3
Evaporator temperature	°C	5
Condenser temperature	°C	35
Absorber temperature	°C	35
Desorber temperature	°C	80

Table 3. General thermodynamic performance of the system.

Parameters	Unit	Value
η_{en}	%	33.49
η_{ex}	%	13.31
$Q_{u,PTC}$	kW	5417
Q_{PVT}	kW	601.3
$\dot{W}_{t,ORC}$	kW	1009
$\dot{W}_{TEG}$	kW	194.5
P_{PVT}	kW	69.48
COP	-	1.097
$Q_{cooling}$	kW	165
$\dot{m}_{H_2}$	kg/day	542.3
$\dot{m}_{freshwater}$	kg/s	4.558
$\dot{Ex}_{d,tot}$	kW	56780

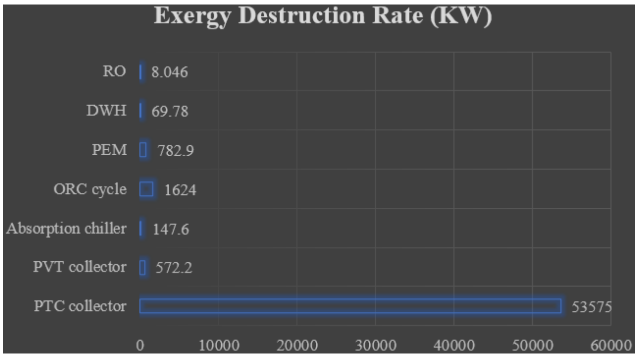

Fig. 2. The amount of exergy destruction rate in different parts of the system.

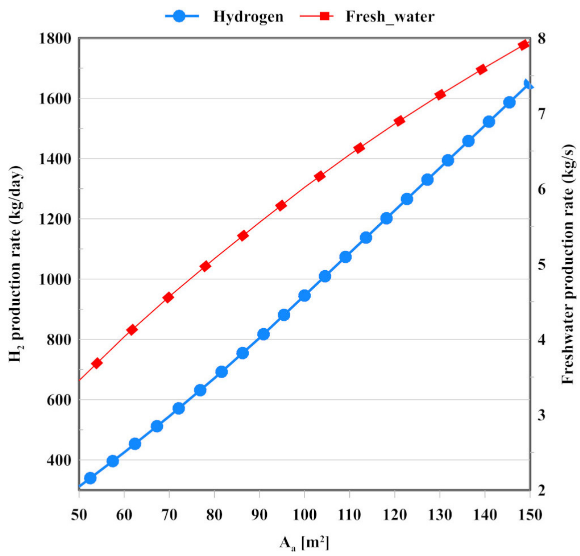

Fig. 3. The effect of the total area of PTC solar collector on the amount of hydrogen and freshwater generated by the system.

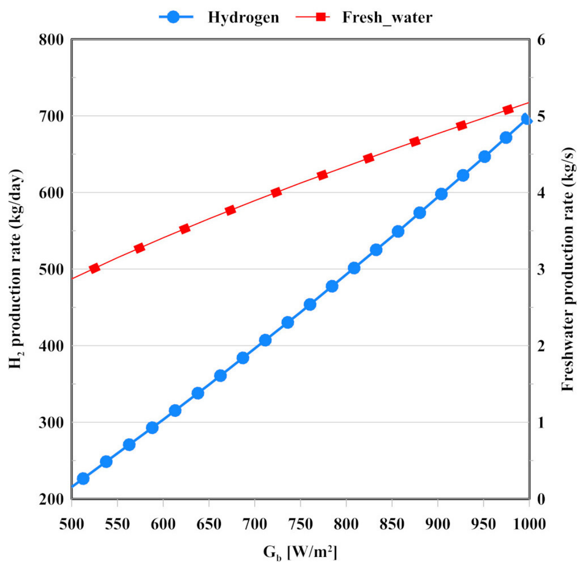

Fig. 4. The effect of the PTC solar radiation on the amount of hydrogen and freshwater generated by the system.

Figure 5 depicts the influence of the PVT collector area on the amount of hydrogen and freshwater production rate of the system. There ate three power production equipment in the studied system. One of them is the PVT solar collector, the other one is the ORC cycle turbine and the last one is the TEG unit. Increasing the PVT solar collector area, increases the amount of power generated by the PVT collector. Therefore, the total amount of power generated by the system rises. It should be noted that the amount of power generated by the PVT solar collector is not as much as the other two equipment. When the PVT solar area changes about three times, the amount of hydrogen generated in the system rises 5.6% and the amount of freshwater generated in the system rises 2.78%.

The influence of PVT collector solar radiation changing on the amount of hydrogen and freshwater generation rate is depicted in the Figure 6. When the solar radiation rises, the amount of hydrogen generated by the PEM electrolyzer varies from 531.2 kg/day to 549.7 kg/day and the amount of freshwater produced by the RO unit changes from 4.511 kg/s to 4.589 kg/s. The reason of rise in the amounts of hydrogen and freshwater production rates is due to this fact that solar radiation increasement leads to the increasement in the amount of the power produced by the PVT solar collector.

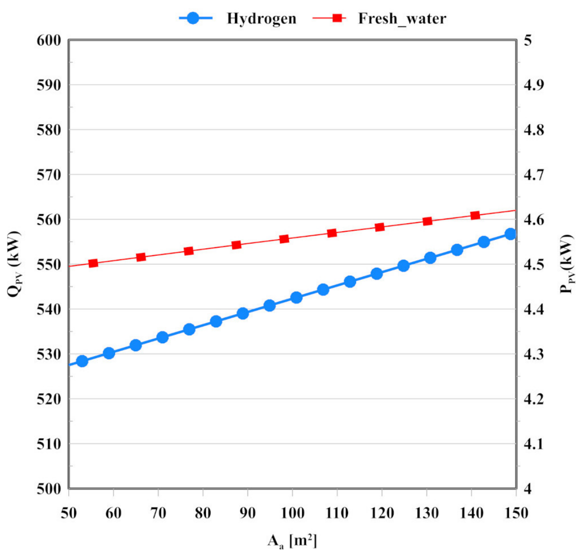

Fig. 5. The effect of the total area of PVT solar collector on the amount of hydrogen and freshwater generated by the system.

Figure 7 depicts the influence of ORC turbine inlet temperature on the amount of hydrogen produced by the PEM electrolyzer and the amount of freshwater produced by the RO desalination unit. When the turbine inlet temperature rises, both hydrogen and freshwater production rates show an increasing trend. By turbine inlet temperature increase from 393 K to 453 K, the hydrogen generation rate goes up from 518.7 kg/day to 555.4 kg/day and the freshwater production rate rises from 4.458 kg/s to 4.613 kg/s. The PEM electrolyzer and the RO desalination unit, both are dependent of the amount of the power generated by the system. The system produces power by the ORC turbine, TEG unit and the PV/T collector. The turbine inlet temperature has no effect on the amount of power produced by the PV/T collector but it increases the total net power generated by the ORC cycle. Therefore, the hydrogen and the freshwater rates increase.

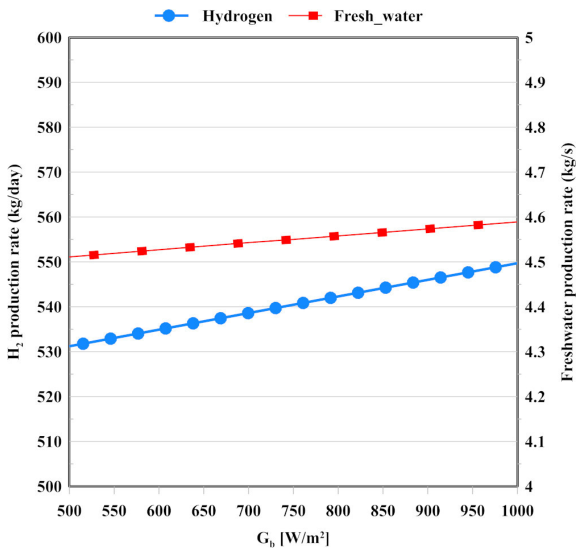

Fig. 6. The effect of the PVT solar radiation on the amount of hydrogen and freshwater generated by the system.

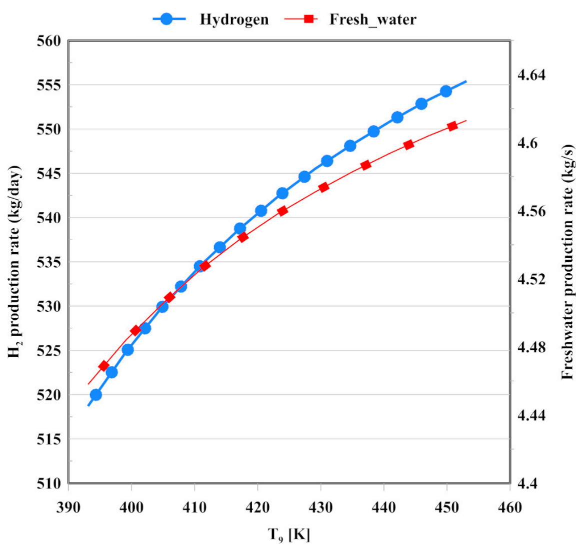

Fig. 7. Effect of turbine inlet temperature on the amount of hydrogen and freshwater production rate.

Figure 8 displays the influence of using different working fluids in the ORC cycle on the performance of the system. Five different working fluids including R141b, neopentane, n-hexane, n-octane and steam have been investigated. The only reason of choosing these working fluids is their operation in the defined working conditions of the ORC cycle. As it is clear in the Figure 8, R141b shows the highest amount of the hydrogen and freshwater production rates. The reason of higher rates is the higher turbine power production by using the R141b working fluid.

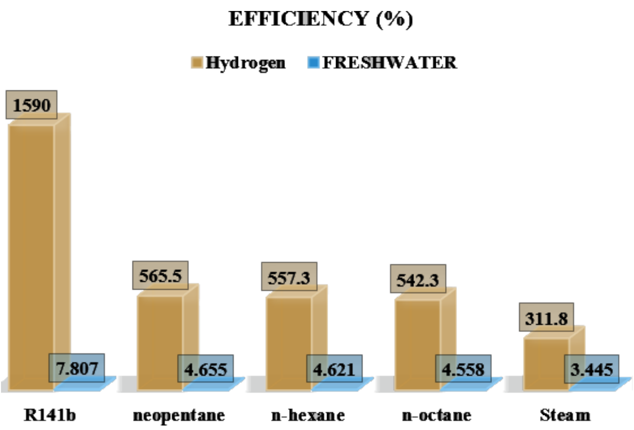

Fig. 8. Effect of different working fluids on the amount of hydrogen and freshwater production rates.

5 Conclusion

In this study, a multigeneration system was investigated that uses PTC solar collector and the PV/T solar collector as its main energy sources. This system produces several outputs including power, cooling, hot water, freshwtare and hydrogen. All the system is analyzed and simulated by using the EES software. The influences of various parameters on the efficiency of the system is explored and the following results are obtained:

- The highest amount of exergy destruction is related to the PTC collector, ORC cycle and PEM electrolyzer, according to an analysis of the exergy destruction of the main cycles.
- For both of the solar collectors, by increasing the collector area, the hydrogen and freshwater production rate of the system rises.
- Increasing the solar radiation, hydrogen and freshwater production rate result in rising trend.
- The ORC turbine inlet temperature rising leads to the increase in the hydrogen and freshwater production rate.
- Investigating different working fluids in the ORC cycle proves that R141b shows the best performance from hydrogen and freshwater production rates point of view.

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