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Exergy Cost Accounting Analysis of New Hybrid Solar Organic Rankine Cycle-MSF Desalination System for Pasabandar Region in Gwadar Bay

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Abstract

An energy system affordable plan selection using renewable energy is a significant problem for designing and manufacturing these systems. The fault detection and thermoeconomic diagnosis in the combined solar Rankine cycle and multi-stage flash (MSF) desalination system is analyzed. In the suggested energy system, the linear parabolic solar collector is utilized as a heat source for the organic Rankine cycle, the domestic hot water, and the multi-stage-flash desalination system. First, the energy balances and exergy analysis are implemented in the considered system, the energy value and exergy parameter are calculated. The exergy cost parameters are calculated for all parts and streams with the thermoeconomic and exergy cost accounting investigation. Finally, the thermoeconomic diagnosis is performed, and the malfunction of each component is evaluated, and the effect of each component's irreversibility on the other part is investigated. Results show that the linear parabolic solar collector has the maximum malfunction. Still, the condenser in the organic Rankine cycle is the most effective component on irreversibility increment among its counterparts..

Keywords: *Desalination; exergy cost accounting; hybrid solar; malfunction; organic rankine cycle.*

1. Introduction

Nowadays, a decrease in fossil-fuel consumption is one of the significant challenges. Consequently, the investigation of supplementary strategies for reaching the United Nations Sustainable Development Goals on energy has long been initiated. As the fundamental source of renewable energy globally, solar energy is the primary source of all available energy on the earth. Same other energies, it can be converted into different energy types (like heat and electricity). Many research types have been performed in recent years, identifying the importance of replacing fossil fuels with renewable energy.

Omar et al. [1] presented a review of the solar Rankine cycle and its characteristics. In their research, the influence of different working fluids and utilizing solar energy were considered. The investigation of the solar energy potential for providing electricity and desalinated water in UK domestic applications was done by James et al. [2]. In the research, the authors presented a life-cycle analysis of the system and according to the total electrical power output and cost, the annual performance of the system was evaluated. They found that tracking concentrating parabolic-trough (PTC) collectors were to be very similar in performance to non-tracking non-concentrating evacuated-tube (ETC) collectors with an average power output of 89 W vs. 80 W.

John et al. [3] reviewed the various solar energy technologies used in different water desalination systems. In their study, the authors compared the direct and indirect solar desalination technologies and selected the direct solar-desalination systems as the best efficient system. Baltasar et al. [4] proposed the best solar desalination system design for given ranges of about 1000–5000 m^3/day. In their proposed system, the reverse osmosis desalination system and the solar organic Rankine cycle were combined. Guanghui et al. [5] proposed reverse osmosis (RO) desalination system operated by wind energy and a solar-powered organic Rankine cycle (ORC). In their study, the authors presented that the condenser temperature and turbine inlet pressure have an essential role in water production. Agustin et al. [6] suggested the different recommendations for combined ORC and solar RO desalination system (SORC). In their paper, the authors found that the linear solar collectors (linear Fresnel concentrators or parabolic troughs) were suitable for incrementing overall thermal performance. The feasibility of using solar desalination in Iran was studied by Shive et al. [7]. In their study, the topography, climate, and water shortage status in Iran were considered, and some of the solar water desalination technology was investigated. The results showed that the fossil fuels used as the heat source for water desalination in the desalination plants centralized in the southern coastal regions. Ratha et al. [8] analyzed a tri-generation system driven by solar energy. The analysis was done with IPSEpro software and verified with experimental data. The tri-generation arrangement produced about 1MW electricity, 234 tons/day of distilled water, and 194 Ton of refrigeration. Nafey et al. [9] performed the combined solar ORC and RO process's design and performance analysis. In their research, the effect of various working fluids on exergy and cost factors was studied. Diab et al. [10] studied the integrated Rankine cycle and solar-based multi-stage flash (MSF)desalination. The results showed that the significant part (about 75 percent) of exergy destruction was related to the MSF unit. Mohamed et al. [11] evaluated a multi-stage flash brine recycled distillation process (MSF-BR) driven by solar energy and performed the thermo-economically analysis.

Exergy cost accounting was one of the important ways to analyze energy systems used in their manuscript. Valero et al. [12-13] have introduced this approach. In this method, Valero proposed the exergy cost accounting and the thermoeconomic method for energy system analysis. In [1], Valero showed the fundamental necessities for calculating the exergy costs and thermoeconomic costs of energy systems. In the next paper [13], Valero presented thermoeconomic analysis applications in energy systems. In the other research, Sajjad et al. [14] studied the energy systems malfunctions and faults and suggested an energy systems thermoeconomic diagnosis nominated Thermoeconomic Input-Output Analysis(TIOA). Alicia et al. [15] presented a thermoeconomic investigation for the cement manufacturing process. In their study, the most inefficient processes were identified and tried to overcome this problem.

This paper proposes a new novel combined energy system, including the organic Rankine cycle, domestic hot water producer, and seawater desalination system. In this system, the linear parabolic solar collector is utilized as a heat source, and energy storage is employed to stabilize the system's stable operation. Therefore, in this manuscript, the linear parabolic solar collector is chosen as a heat source for power, domestic water, and desalinated water production in one of the proper cities in Gwadar Bay. The Pasabandar, one of the small regions of Chabahar in Gwadar bay, is selected for the installation of this proposed system. The exergy and energy analysis for all of the components is performed to evaluate the combined energy system. Exergy destruction in energy systems reduce the overall efficiency. In this study, the thermoeconomic diagnosis method is implemented to detect each component's inefficiencies in the proposed designs. Thus, the amount of inefficiencies and their location is present with the thermoeconomic diagnosis method. Other techniques zoom on each component's irreversibility and endeavor to reclaim it. Each component's hidden effects on other components' irreversibility are examined in this manuscript. Thus, the governing results offer a suitable method for identifying significant unknown inefficient components.

2. Modelling

2.1 System Description

The suggested hybrid solar system schematic is shown in **Error! Reference source not found.**. The proposed system consists of the solar cycle, Organic Rankine cycle, Multi-stage flash distillation cycle, and domestic heat water producer. In the basic solar cycle (5-6-7-8-9-10), Therminol-66 is used as the working fluid, and thermal storage is forecasted for steady-state operation in different solar conditions. The working fluid is heated by the solar energy unit and then stored in the tank. The heat from the exhaust gases from the combustion of the turbine inside a heat exchanger is added to the operating fluid, and this heat is used to increase the temperature of the water used in the residential units as well as to produce fresh water in the MSF units. For domestic hot water production (17-18), a heat exchanger uses to heat the feed water (to 60°C). In the Organic-Rankine cycle (1-2-3-4), the water-ammonia mixture is used as a working fluid, and a heat exchanger provided the required thermal energy. For desalination of seawater, the multi-stage-flash desalination system (MSF) is proposed. One heat exchanger provided the requires heat for seawater vaporization in different stages. The Pasabandar, one of Chabahar regions in Gwadar bay, is selected for the proposed cycle location. The detailed information about Pasabandar is presented in Table 1. The required analyses of each component are

Table 1. The detail of Pasabandar region.

parameter	value
Longitude	25°04′01″N
Latitude	61°24′44″E
population	1093

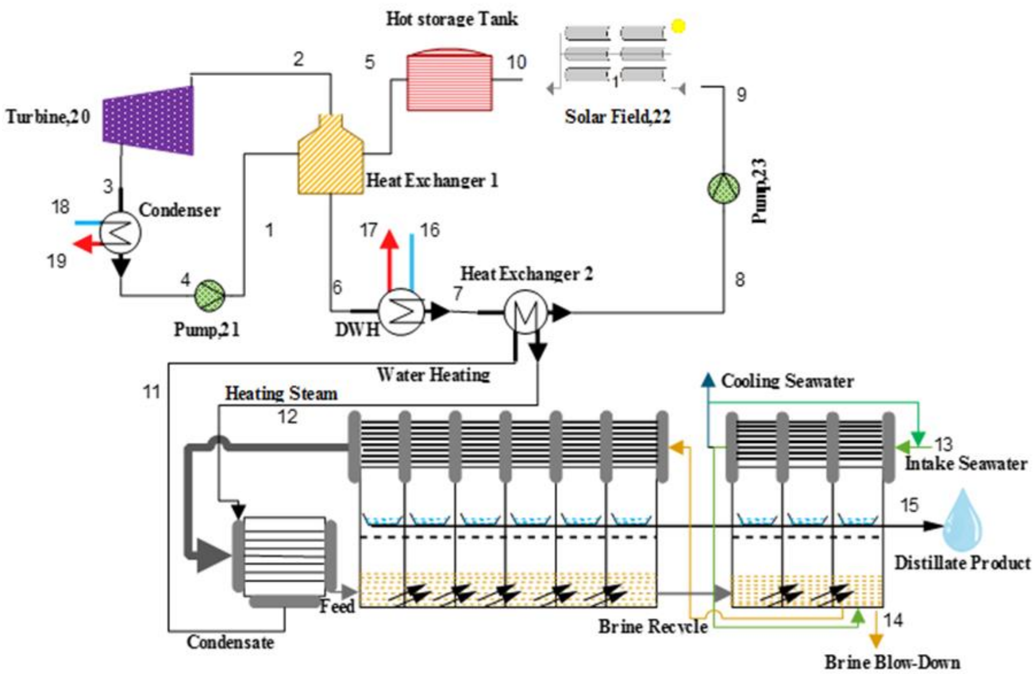

Figure 1. Schematic of the hybrid system

2.2 Energy Analysis

- Therminol Cycle (Solar Circuit)

In the Therminol-66 cycle, the linear parabolic solar collector is used as the heat absorber. Detailed information about these types of collectors can be found in [16], and in this section, only the required formulation is considered. In general, the absorbed solar heat in a linear parabolic collector can be calculated with Eq.(1).

$$Q_u = E_R A_u [S - \frac{A_{re}}{A_0} U_L (T_{10} - T_0)] \quad (1)$$

The absorbed solar radiation per unit of aperture area, the un-shaded area, and the area of the receiver can be calculated respectively, as bellow:

$$S = I_{ap} \tau \rho \alpha \quad (2)$$

$$A_u = (w - D) l \quad (3)$$

$$A_{re} = \pi D_0 l \quad (4)$$

The heat removal factor is calculated from the next equation:

$$E_R = \frac{\dot{m} c_{pr}}{A_r U_L} [1 - \exp\left(\frac{A_{re} U_L F'}{\dot{m} c_P}\right)] \quad (5)$$

Where,

$$F' = \frac{\frac{1}{U_L}}{\frac{1}{U_L} + \frac{D_O}{H_{te} D_i} + (\frac{D_O}{2k} ln \frac{D_O}{D_i})} \quad (6)$$

The heat losses in hot storage can be presented in the unit area of the tank surface as below:

$$\dot{Q}_{hs} = U(T_{11} - T_0) \quad (7)$$

For heat exchangers used in the organic Rankine cycle, domestic heat water, and desalination systems, the following energy balance equations can be used:

$$\dot{m}_{sc}(h_5 - h_6) = \dot{m}_{rc}(h_2 - h_1) \quad (8)$$

$$\dot{m}_{sc}(h_6 - h_7) = \dot{m}_w(h_{18} - h_{17}) \quad (9)$$

$$\dot{m}_{sc}(h_7 - h_8) = \dot{m}_r(h_{12} - h_{11}) \quad (10)$$

- Organic-Rankine cycle

In the organic Rankine cycle, the primary energy balance equation used in the classic steam cycle can be applied. The output power from the steam turbine, the input power to the pump, and total net power is calculated as below:

$$\dot{W}_t = \dot{m}_{rc}(h_2 - h_3) \quad (11)$$

$$\dot{W}_p = \dot{m}_{rc}(h_1 - h_4) \quad (12)$$

$$\dot{W}_{net,rc} = \dot{W}_{t,rc} - \dot{W}_{p,rc} \quad (13)$$

The isentropic turbine efficiency is defined as below:

$$\eta_t = \frac{(h_2 - h_3)}{(h_2 - h_{3s})} \quad (14)$$

The absorbed heat rate in the heat exchanger 1 and the rejected heat rate in the condenser are given by:

$$\dot{Q}_{boil} = \dot{m}_{rc}(h_1 - h_2) \quad (15)$$

$$\dot{Q}_{cond} = \dot{m}_{rc}(h_3 - h_4) \quad (16)$$

- Desalination system

MSF is one of the thermal desalination technologies that used widely in the world. The brine recirculation type of this technology is used for seawater desalination in this manuscript. In brine recirculation MSF, the hot brine can flow freely and flash in a set of effects. The required heat for the brine heating of feed-water is provided from the Therminol cycle. The hot brine flashes in the stages, and the formed vapor's latent heat recovers by feed and brine recycle flow in the condenser. The surplus heat given to the system is rejected to the sea in the condenser.

The feed to distilled water mass flow ratio can be examined as the function of thermal and mechanical parameters as below [17],

$$\frac{M_f}{M_d} = \frac{L_v}{c_P \Delta F} + \frac{N-1}{2N} \quad (17)$$

Where the flashing temperature range, ΔF is given by:

$$\Delta F = T_h - T_{bN} = (T_{b1} - T_{bN}) \frac{N}{N-1} \quad (18)$$

The maximum brine concentration limits the rate of external feed per unit of product (M_f/M_d) as bellow:

$$\frac{M_f}{M_d} = \frac{y_{bN}}{y_{bN} - y_f} \quad (19)$$

The total required heat for water desalination can be calculated by:

$$\frac{\dot{Q}_{des}}{M_d} = \frac{M_r}{M_d} c_P (T_h - T_0) = L_v \frac{T_h - T_0}{\Delta F} \quad (20)$$

Where,

$$\dot{Q}_{des} = \dot{m}_{sc}(h_8 - h_7) \quad (21)$$

2.3 Exergy Analysis

The highest available work that can be obtained from the particular flow is named exergy. This idea is used in the assessment of irreversibility in any system. For the particular flow, the exergy can be computed as following [18]:

$$e_f = (h - h^*) - T_0(s - s^*) + \sum_{i=1}^{n} y_i(\mu_i^* - \mu_i^0) \quad (22)$$

The first two terms show the physical exergy, and the next term indicates the chemical exergy. For a control volume, the exergy equation is represented as bellow:

$$\frac{dE}{dt} = \sum \left(1 - \frac{T_0}{T}\right) Q + \left(W - P_0 \frac{dv}{dt}\right) + \sum \dot{m}_i e_i - \sum \dot{m}_e e_e - \dot{E}_D \quad (23)$$

Based on fuel and product exergy, the exergy destruction in each component is evaluated:

$$\dot{E}_D = \dot{E}_{fuel} - \dot{E}_{product} \quad (24)$$

Table 2. Exergy equations of each component in the system.

Component	Fuel exergy (kW)	Product exergy (kW)
Solar field	$\dot{E}_{22}$	$\dot{E}_{10} - \dot{E}_9$
Hot storage tank	$\dot{E}_{10}$	$\dot{E}_5$
Heat exchanger 1	$\dot{E}_5 - \dot{E}_6$	$\dot{E}_2 - \dot{E}_1$
DWH	$\dot{E}_6 - \dot{E}_7$	$\dot{E}_{17} - \dot{E}_{16}$
Heat exchanger 2	$\dot{E}_7 - \dot{E}_8$	$\dot{E}_{12} - \dot{E}_{11}$
Solar pump	$\dot{E}_{23}$	$\dot{E}_9 - \dot{E}_8$
Desalination unit	$\dot{E}_{12} + \dot{E}_{13}$	$\dot{E}_{14} - \dot{E}_{15}$
Turbine	$\dot{E}_2 - \dot{E}_3$	$\dot{E}_{20}$
Condenser	$\dot{E}_3 - \dot{E}_4$	$\dot{E}_{19} - \dot{E}_{18}$
Rankine pump	$\dot{E}_{21}$	$\dot{E}_1 - \dot{E}_4$

The above definitions describe that each component exergy balance equations in steady-state condition are determined and mentioned in Table 2

Exergetic efficiency is one of the essential parameters for irreversibility evaluation that defined based on the fuel-product definition as bellow:

$$\varepsilon = product/fuel \quad (25)$$

2.4 Thermoeconomic Diagnosis and Exergy Cost Accounting

The thermoeconomic analysis is a fundamental idea that combines the irreversibility and cost principles for evaluating thermal systems. Thermoeconomic variables can be determined based on the investment costs and thermodynamic irreversibilities. The necessary data for thermoeconomic evaluation is obtained from the economic and thermodynamic model, physical structure, and productive system. The physical system defines the components, thermodynamic process (feed or product), mass, heat, and workflows. In the thermoeconomic theory, the economic study as the function of investment, operation, and fuel cost are applied to exergy and energy equations. One of the essential parameters in thermoeconomic evaluation is unit exergy consumption (k), equal to the inverse of exergetic efficiency**.**

The exergy cost ($\dot{E}_i^*$) is another parameter defined as the amount of exergy resources utilized for specific flow production [19]. This parameter can be employed for the evaluation of resource consumption in various exergy flow. The unit exergy cost is defined as follows, based on the above definition:

$$c_i = \dot{E}_i^*/\dot{E}_i \quad (26)$$

The calculations mentioned above are the primary action for the diagnosis of energy systems and thermoeconomic analysis.

In the fuel-product (FP) table definition, the residue and product streams should be determined. Each element ($\dot{E}_{ij}$) describes the product exergy for the component (i) and the fuel exergy of the component (j). After the FP table accounting, the product, P, and irreversibility, I, can be determined. The incoming flows from the environment and other elements are defined as the resources of this component. In the productive and dissipative units, respectively, the cost of fuel and product is calculated as below:

$$C_{F,i} = \dot{E}_{i0}^* + \sum_{j=1}^{n} \dot{E}_{ji}^* \quad (27)$$

$$C_{P,i} = \dot{E}_{0i}^* + \sum_{j=1}^{n} \dot{E}_{ij}^* \quad (28)$$

$$C_{P,i} = R_{i0}^* \quad (29)$$

The cost of residues related to the *j*th productive component is estimated by:

$$C_{R,j} = \sum_i R_{ij}^* \quad (30)$$

Each component product cost is calculated as follows:

$$C_{P,i} = C_{F,i} + C_{R,i} \quad (31)$$

The external resources cost, $C_{e.i}$, is determined by:

$$C_{e,i} = \dot{E}_{i0}^* = \dot{E}_{io} \quad (32)$$

The product unit exergy cost can be decomposed as:

$$c_P = c_P^e + c_P^r \quad (33)$$

The variety of the malfunction (MF), the unit exergy consumption (Δk), and the fuel impact (ΔF) are the essential indicators for diagnosis evaluation. The parameters can be determined as follows: [20]

$$\Delta k = k_{op} - k_{ref} \quad (34)$$

$$MF = \Delta k \times \dot{E}_{ref} \quad (35)$$

$$\Delta F = c_F \times \Delta k \times \dot{E}_{ref} \quad (36)$$

The malfunction parameter (MF) shows the exergetic performance variation between reference and operating conditions in any element and can deliver negative or positive values [21]:

$$MF > 0 \rightarrow \left[\left(\frac{1}{\varepsilon}\right)_{op} - \left(\frac{1}{\varepsilon}\right)_{ref}\right] \times \dot{E}_{ref} > 0 \rightarrow \varepsilon_{op} < \varepsilon_{ref} \quad (37)$$

$$MF < 0 \rightarrow \left[\left(\frac{1}{\varepsilon}\right)_{op} - \left(\frac{1}{\varepsilon}\right)_{ref}\right] \times \dot{E}_{ref} < 0 \rightarrow \varepsilon_{op} > \varepsilon_{ref} \quad (38)$$

The extra fuel consumption in each element can be calculated by the fuel impact (ΔF) for anomaly detection in the various segments. In the process, dysfunction by the malfunction of other elements that created the consumption of the more local source to achieve the different generation required by the other elements is given by [12]:

$$DF_i = (k_i - 1)\Delta P_i \quad (39)$$

3. Results & Discussion

The hybrid solar configuration consists of organic Rankine cycle, domestic heat water producer and multi-stage-flash (MSF) desalination method is suggested for the Pasabandar area in Gwadar bay. The design variables for MSF are presented in Table 3.

Table 3. Proposed hybrid system input parameters.

parameter	value
Ambient pressure , bar	1.013
Ambient temperature , ℃	15
Feed water salinity, ppm	35000
Top brine temperature, ℃	82
Sun temperature, ℃	5505

Based on the above input variables, the computation has been completed, and the derived conclusion is displayed in Table 4. The mathematical calculation has been performed using Matlab code and Ebsilon software based on the above input parameters. The compression of results is presented in Table 4, too. Matlab code results have a good agreement with Ebsilon simulation. The results show that, the proposed system delivered 12 m^3/day distillated water, 338 kW electrical power, 0.5581 kg/s domestic hot water (60^{oc}) and 11.36 kg/s industrial feed hot water.

The exergy cost investigation results for the different components are shown in Table 5. Results confirm that the MSF system has the highest unit exergy consumption and is the most ineffective element. Based on these conclusions, the elements can be arranged from efficient to the inefficient as condenser, thermal storage, heat exchanger 2, turbine, pump, heat exchanger 2, solar field, domestic heat water producer, solar pump and desalination system.

The exergy cost in the various elements is displayed in Figure 2. The conclusions confirm that the solar field affects each element's exergy cost and the MSF desalination has the highest exergy cost.

This preliminary investigation introduces the MSF desalination as the origin of irreversibility, but advanced evaluation should be implemented for precise ineffective element detection. For this precise advance analysis, the changes in the concentration of ammonia-water mixture in organic Rankine cycle should be applied. One of this changes that called operation condition is shown in Table 6 .

Table 4. The results of energy balance equations.

Parameter	Value		
	Code	Ebsilon Simulation	Error
Distillated water production, $\dot{m}_d$ (kg/s)	0.1488	0.1522	2.233
Power production, w_{out} (kW)	337.5	337.5081	0.002
Domestic water heating, $\dot{m}_{DWH}$ (kg/s)	0.5581	0.5604	0.417
Industrial water heating, $\dot{m}_w$ (kg/s)	11.36	11.3631	0.027

Table 5. The exergy cost analysis for different equipment.

Equipment	Turbine	Heat exchanger 1	ORC-pump	thermal Storage	Solar Field	Solar Pump	Heat Exchanger 2	Desalination	Condenser	Domestic Heat Water Producer
Product [kW]	337.5	512	7.7	1133	1160.6	0.1	45.4	0.6	150.5	7.4
Fuel [kW]	368.1	1062.3	9.5	1161	2782	0.4	48.4	63.7	151.6	22
Irreversibility [kW]	30.6	550.3	1.8	28	1621.4	0.3	3	63.2	1.1	14.6
Unit Exergy Consumption	1.090	2.075	1.237	1.025	2.397	3.830	1.066	109.824	1.007	2.982

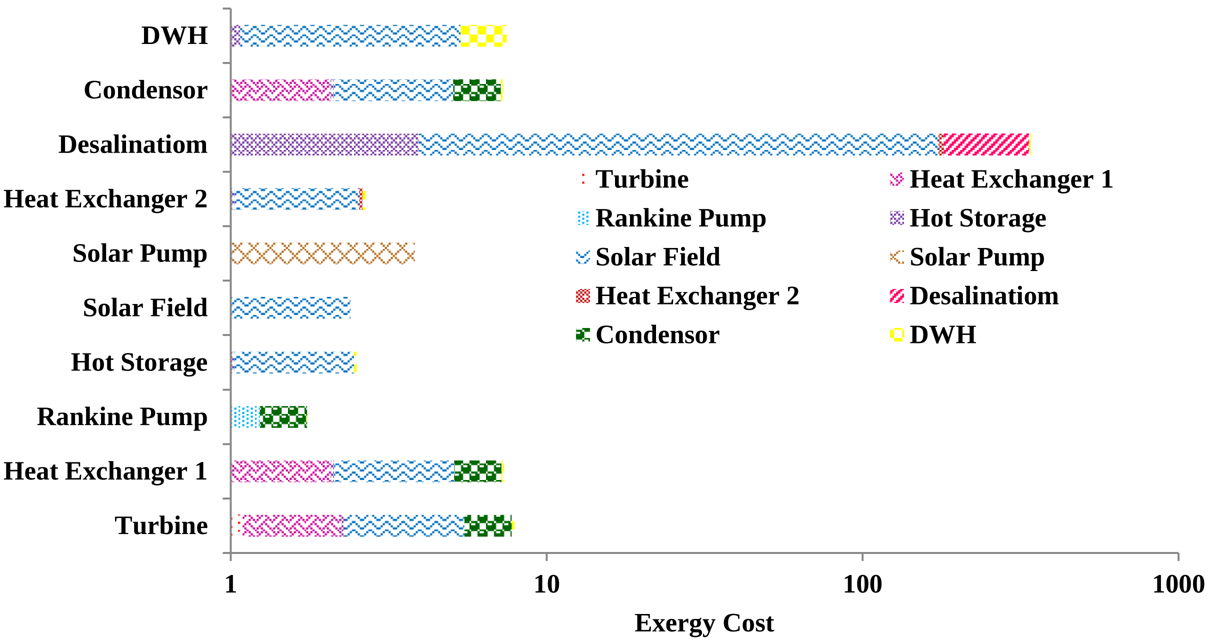

Figure 2. The exergy cost decomposition for different component in reference system.

Table 6. Modeling result of operation system.

Parameter	Value
Ammonia-Water Concentration	0.5
Distillated water production, $\dot{m}_d$ (kg/s)	0.1488
Power production, w_{out} (kW)	101.6
Domestic water heating, $\dot{m}_{DWH}$ (kg/s)	0.5581
Industrial water heating, $\dot{m}_w$ (kg/s)	5.213

At reference and operating conditions, the comparison of exergy cost parameters are collected in Table 7. Results present that decreasing in ammonia-water concentration in organic Rankine cycle decreased the irreversibility in the turbine, heat exchanger, Rankine pump, thermal storage and solar field, effectively.

The amount and location of anomalies that produced the exergetic efficiency decrease are the thermoeconomic diagnosis's main object. Based on the definition of malfunction and irreversibility, these parameters can be determined for each element from equation (35) to assess the anomaly's impacts.

The thermoeconomic diagnosis conclusions for the suggested hybrid arrangement is shown in Table 8. Conclusions confirm that the unit exergy cost in the operating state is lower than the reference state, and thus, the variation in ammonia-water concentration decreased the resource consumption in the operating arrangement. For a better comparison between the various element's malfunction values, the proper diagram is displayed in Figure 3. Considering Table 8 and Figure 3 reveal that the malfunction of the heat exchanger 1, the turbine and Rankine cycle's pump have negative values. These negative values confirm that these elements have better efficiency in operating condition. In general, results confirm that the fuel impact in the operating system is decreased about -1280 kW compared to the reference system and fewer resources are utilized in the new system.

The malfunction decomposition is the important parameter that specifies the effect of each component on total malfunction. This parameter is displayed in Figure 4. Conclusions displayed that the environment has the most effect on the positive malfunction in the solar field. With the same analysis, the hot storage tank has the major role on malfunction decrement in heat exchanger 1; the heat exchanger 1 has the major role in malfunction increment in the condenser.

Table 7. The operating and reference system Irreversibility and unit consumption.

Process	I [kW]		K	
	Reference scenario	Operation scenario	Reference scenario	Operation scenario
Turbine	30.6	8.9	1.0907	1.0876
Heat exchanger 1	550.3	105.	2.0748	1.3986
Rankine Pump	1.8	1.3	1.2371	1.2133
Thermal Storage	28.0	13.8	1.0247	1.0314
Solar Field	1621.4	1051.5	2.3970	3.3238
Solar Pump	0.3	0.3	3.8299	3.8299
Heat Exchanger 2	3.0	3.0	1.0658	1.0658
Desalination	63.2	63.2	109.8235	109.8235
Condenser	1.1	90.2	1.0073	2.3061
DWH	14.6	14.6	2.9815	2.9815

Another necessary index that defines the detailed irreversibility increase in different elements (produced by malfunctions of another element) is dysfunction. Figure 5 confirms that the condenser makes a 635.6 kW irreversibility increase in the solar unit, but the solar unit has adverse impacts on the other element's irreversibility. These issues confirm that the irreversibility in the solar unit can be reduced significantly by condenser improvement. Figure 5 reveals that 829.6 kW irreversibility decrease in the solar unit is produced by the heat exchanger 1.

Table 8. The thermoeconomic diagnosis result for different component.

Process [kW]	Turbine	Heat exchanger 1	Rankine Pump	Hot Storage	Solar Field	Solar Pump	Heat Exchanger 2	Desalination	Condenser	DWH	Total
Malfunction	-1	-346.2	-0.2	7.6	1075.6	0	0	0	195.5	0	931.2
Irreversibility variation	-21.7	-445.3	-0.5	-14.2	-569.9	0	0	0	89.1	0	-962.6
Total Product variation	-235.9	0	0	0	0	0	0	0	-81.5	0	-317.4
Malfunction cost	-16	-1187	-0.2	25.4	1075.6	0	0	0	916.5	0	814.3
Total Product variation cost	-1208.9	0	0	0	0	0	0	0	-885.4	0	-2094.2

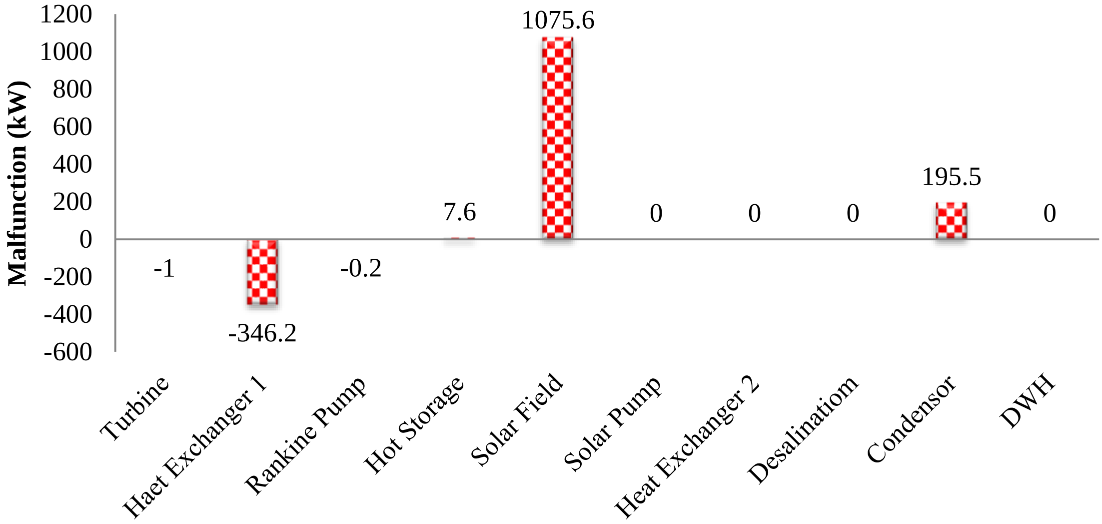

Figure 3. The different components Malfunction of the proposed cycle

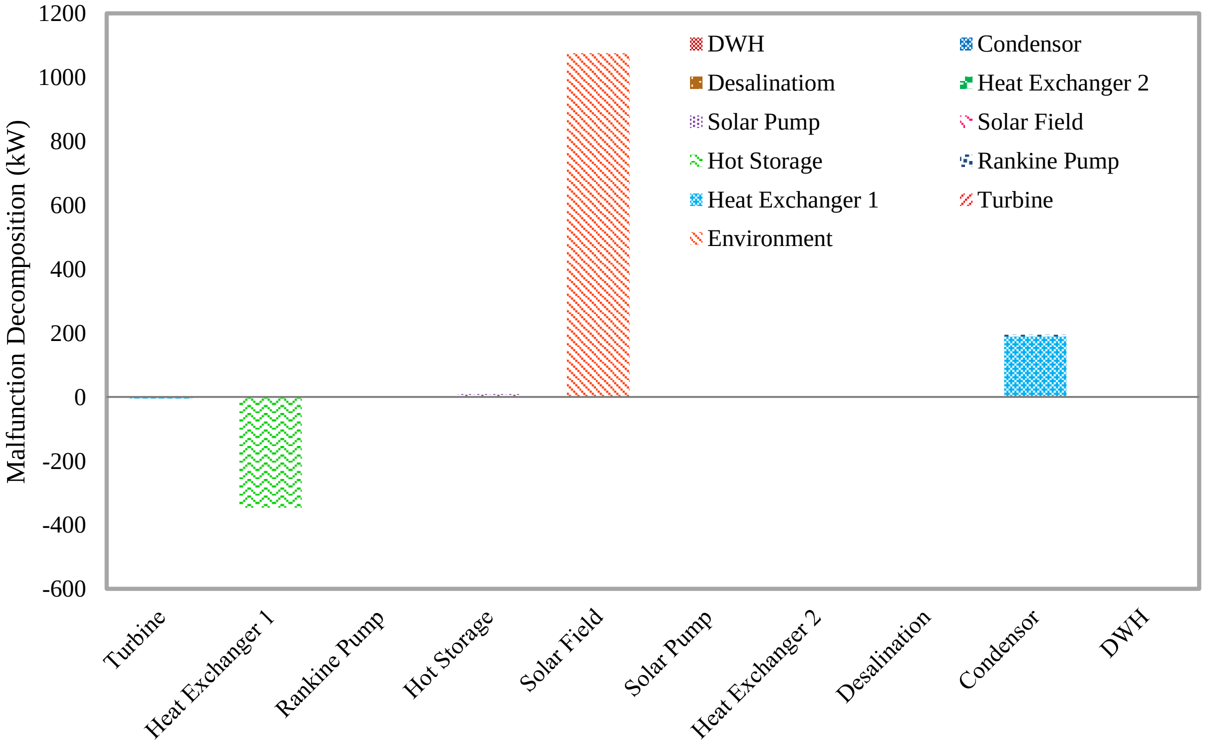

Figure 4. The malfunction decomposition.

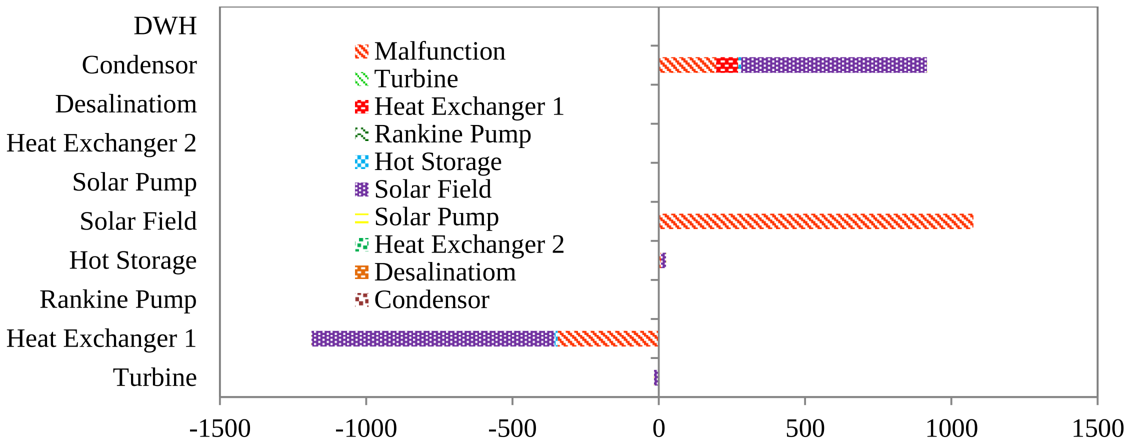

Figure 5. Dysfunction analysis of the system.

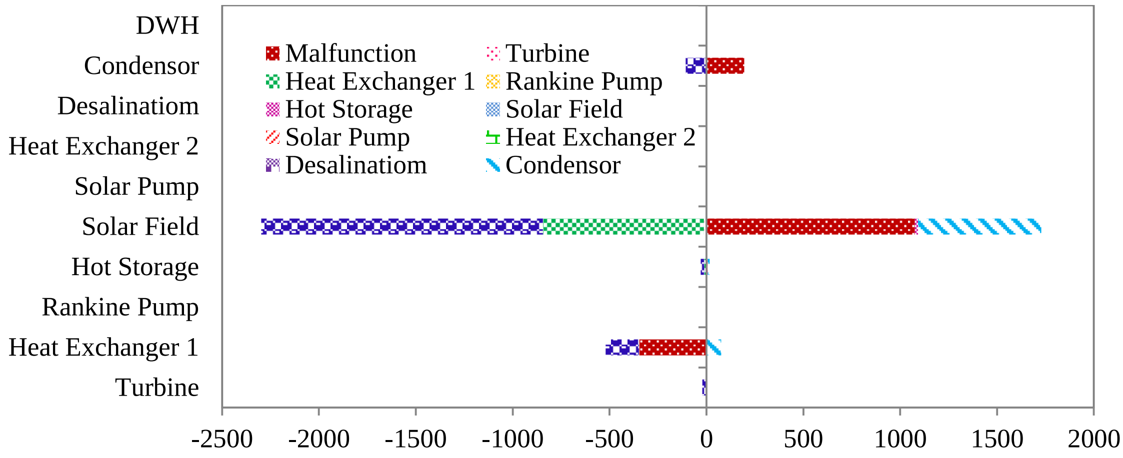

Figure 6. Dysfunction and malfunction analysis.

For a better study, the malfunction and dysfunction indications are connected together and are shown in Figure 6. Conclusions confirm that, in the solar field, 635.4 kW irreversibility increase is generated by malfunction of the condenser and about 830 kW irreversibility decrement related to the heat exchanger 1. The adverse irreversibility in the solar unit, condenser, and heat exchanger 1 shows that the malfunction reduced the additional resource consumption in these elements.

4. Conclusion

In this research, one of the applicable hybrid solar systems consists of an organic Rankine cycle, domestic heat water producer and multi-stage-flash desalination system is proposed for Pasabandar, a region in Gwadar bay. The exergy cost accounting and malfunction diagnosis are implemented to assess different components in the suggested system. Unlike the exergoeconomic method that specifies the inefficient component based on its irreversibility; these indexes examine the hidden impact of each element on irreversibility increase and extra fuel consumption in other elements; thus can introduce the actual inefficient equipment. A large amount of the malfunction calculated in the solar field presents that there is some diagnosis in this equipment. Conclusions present that the condenser has the minimum unit exergy cost, but malfunction-dysfunction analysis shows that this component has the major impact on the irreversibility increment in the other equipment. Thus, the condenser is the main contributor for total malfunction increasing in the system and for the better performance, this component should be improved.

Nomenclature

A_{re}	area of the receiver (m^2)	F	Exergy of fuel (kW)
A_u	unshaded area of the concentrator aperture (m^2)	H_{te}	heat transfer coefficient inside the tube (W/m^2 K)
C	Total Exergy Cost of the flow (kW)	I	Irreversibility (kW)
c	Total unit exergy cost of the flow (kW/kW)	I_{ap}	the effective incident radiation (W/m^2)
Ce	Exergy cost of flow due to irreversibilities (kW)	K	conductivity (W/m K)
c_e	Unit exergy cost of flow due to irreversibilities (kW/kW)	k	Unit Consumption F/P (kW)
c_F	Unit exergy cost of fuel (kW/kW)	L_v	average latent heat of vaporization (kJ/kg)
c_P	Unit exergy cost of product (kW/kW)	l	concentrator length
c_p	mean specific heat (kJ/kg K)	M_d	mass rate of distillate (kg/h)
$c_{P,e}$	Unit production cost due to irreversibility (kW/kW)	M_f	mass rate of feed (kg/h)
$c_{P,r}$	Unit production cost due to residues (kW/kW)	M_r	mass rate of recirculated brine (kg/h)
Cr	Exergy cost of flow due to residues (kW)	$\dot{m}$	mass flow rate (kg/s)
c_r	Unit exergy cost of flow due to residues (kW/kW)	MF	Malfunction (kW)
D	absorber envelope outer diameter (m)	MF*	Malfunction cost (kW)
D_i	absorber inside diameter (m)	N	total number of stages or effects

D_o	absorber outside diameter (m)	P	Exergy of product (kW)
DF	Dysfunction (kW)	R_{ij}^*	cost of the residue dissipated by the ith component that is related to the jth component production
DI	Irreversibility variation (kW)	R_{i0}^*	cost of waste
DPs	Total Product variation (kW)	S	absorbed solar radiation per unit of aperture area (W/m^2)
DP*	Total Product variation cost (kW)	T	temperature (K)
$\dot{E}$	Exergy of flow (kW)	U_L	overall heat transfer coefficient (W/m^2 K)
$\dot{E}_{i0}^*$	cost of the external resources entering the component	w	width of receiver (m)
$\dot{E}_{0i}^*$	cost of the final products of the system	y	mass fraction of salts in brine
	Greek letters		
α	absorptivity	τ	effect of angle of incidence
ρ	specular reflectance of the concentrator	ε	Exergetic efficiency
	Subscript		
b	brine	r	recirculated brine
b1	brine in first effect	rc	Rankine cycle
bN	brine in last effect	ref	reference
f	feed	sc	Solar cycle
op	operating	0	Environment

References

[1] O. Aboelwafa, S. K. Fateen, A. Soliman, I. M. Ismail, "a review on solar Rankine cycles: Working fluids, applications, and cycle modifications" Renewable Sustainable Energy Rev., 82, 868–885, 2018.

[2] J. Freeman, K. Hellgardt, C. N. Markides, "an assessment of solar-powered organic Rankine cycle systems for combined heating and power in UK domestic applications", Appl. Energy, 138, 605–620, 2015.

[3] J. H. Reif, W. Alhalabi, "Solar-thermal powered desalination: Its significant challenges and potential", Renewable Sustainable Energy Rev., 48, 152–165, 2015.

[4] B. Peñate, L.G. Rodríguez, "Seawater reverse osmosis desalination driven by a solar Organic Rankine Cycle: Design and technology assessment for medium capacity range", Desalination, 284, 86–91, 2012.

[5] G. Xia, Q. Sun, J. Wang, X. Cao, Y. Yu & L. Wang, "Theoretical analysis of a reverse osmosis desalination system driven by solar-powered organic Rankine cycle and wind energy", Desalin. Water Treat., 53, 876–886, 2015.

[6] A. M. D. Torres, L.G. Rodriguez, "Design recommendations for solar organic Rankine cycle (ORC)–powered reverse osmosis (RO) desalination", Renewable Sustainable Energy Rev., 16, 44– 53, 2012.

[7] S. Gorjian, B. Ghobadian, "Solar desalination: A sustainable solution to water crisis in Iran", Renewable Sustainable Energy Rev., 48, 571–584, 2015.

[8] R. Z. Mathkor, B. Agnew, M. A. Al-Weshahi and F. Latrsh, "Exergetic Analysis of an Integrated Tri-Generation Organic Rankine Cycle", Energies, 8, 8835-8856, 2015.

[9] A.S.Nafey , M.A.Sharaf, "Combined solar organic Rankine cycle with reverse osmosis desalination process: Energy, exergy, and cost evaluations", Renewable Energy, 35, 2571-2580, 2010.

[10]D.W. Abueidda and M. Gadalla, "Thermodynamic Analysis of an Integrated Solar-Based Multi-Stage Flash Desalination System", IMECE, USA, 2012.

[11] M. A. S. Eldean, H.E. Fath," Exergy and thermo-economic analysis of solar thermal cycles powered multi-stage flash desalination process", Desalin. Water Treat., 51, 7361–7378, 2013.

[12] A. Valero, L. Serra, J. Uche, "Fundamentals of Exergy Cost Accounting and Thermoeconomics", Part I: Theory, J. Energy Resour. Technol., 128, 1-8, 2006.

[13] A. Valero, L. Serra, J. Uche, "Fundamentals of Exergy Cost Accounting and Thermoeconomics", Part II:Applications, J. Energy Resour. Technol., 128 , 9-15, 2006.

[14] S. Keshavarzian, M. V. Rocco, "Emanuela Colombo, Thermoeconomic diagnosis and malfunction decomposition: Methodology improvement of the Thermoeconomic Input-Output Analysis (TIOA)", Energy Convers. Manage., 157, 644-655, 2018.

[15] A. Valero, A. Abadías, "Thermoeconomic analysis of a cement production plant", *29th international conference on efficiency, cost, optimization, simulation and environmental impact of energy systems*, Slovenia, 2016.

[16] J.A. Duffie, W.A. Beckman, *Solar Engineering of Thermal Processes*,John Wiley & Sons, Inc., 2006.

[17] S. A. Kalogirou, *Solar Energy Engineering Processes and Syste*ms, Second edition, Elsevier Inc, ISBN–13: 978-0-12-397270-5, 2014.

[18] S. Sadri, R. H. Khoshkhoo, M. Ameri, "Optimum exergoeconomic modeling of novel hybrid desalination system (MEDAD-RO)", Energy, 149, 74-83, 2018.

[19] A. Valero, S. Usón, C. Torres and W. Stanek, *Theory of Exergy Cost and Thermo-Ecological Cost, chapter 7 of Thermodynamics for Sustainable Management of Natural Resources*, Springer International Publishing, ISSN 1865-3529, 2017.

[20] V.Verda, "Accuracy level in thermoeconomic diagnosis of energy systems", Energy , 31:32 48–60, 2006.

[21] S. Keshavarzian, M. V. Rocco, E. Colombo, "Thermoeconomic diagnosis and malfunction decomposition: Methodology improvement of the Thermoeconomic Input-Output Analysis (TIOA)", Energy Convers. Manage., 157, 644-655, 2018.