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Environmental Analysis of High Temperature Solar Heat Pump, Case Study of Hot Water Production System With Weather Conditions of Ahvaz

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ABSTRACT

Background: The main purpose of this study is to evaluate the energy consumption quality of the hot water production system with weather conditions of Ahvaz.

Methods: The related simulation is carried out using Aspen HYSYS software, version 10. Then Aspen HYSYS and Matlab software were used for exergy and environmental exergy and environmental exergy analyzes.

Results: According to the study results, the exergy analysis showed that the highest exergy efficiency of the rotating components is related to the K100 compressor with 87.63%. Also, the lowest exergy destruction rate of the rotating components is related to the pump P100 with 0.52 kW. Also, an analysis of the effects of equipment on the environment from the perspective of life cycle assessment (LCA) and the effect of exergy destruction on the environment was conducted on the equipment so that the f_b solar collector had the highest value among other equipment, indicating the greatest environmental effect of the inefficiency of this equipment. Compressor K101 should also be reviewed for LCA due to the high percentage of environmental factors.

Conclusion: The results show that the environmental exergy analysis of the hot water production system can identify inefficient equipments and their impact rate on the environment.

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1. Introduction

The increasing greenhouse gas emission due to improper consumption of different types of energy carriers in the world causes environmental consequences such as increasing global warming. This has environmental effects such as diseases, the need for agricultural water, and the phenomenon of acid rain. The emission of greenhouse gases over a large area has led to an increase in temperature. Global warming has been focused by researchers in recent decades due to its environmental and socio-economic effects as well as its micro and macro planning [1]. Because of economic development and population growth, we have seen a rapid increase in energy consumption during recent years [2]. Extensive use of coal and oil, including natural gas as well asfossil fuels has caused serious air pollution and health problems. For these reasons, thermal energy can be supplied using renewable energy sources. To prevent energy loss is one of the most effective ways to save energy and protect the environment [3, 4]. Nowadays, renewable energy is essetial to decrease fossil fuel consumption and the produced carbon dioxide, which is in part the reason for global warming [5]. A majority of our need for energy can be met by solar energy which is the most reliable source of energy in the world. During the last decade, solar-based technologies have become very popular around the world due to environmental issues. This resulted in a rapid increase in energy prices and consumption of fossil fuels. In the last two decades, the solar heating systems have been used in many areas [6, 7]. In recent decades, researchers have evaluated factory systems in order to prioritize equipment. Exergy analysis in the factories help us to identify the most inefficient process parts of a system in which the energy is wasted [8].

A solar-assisted heat pump system is a special technique to decrease or eliminate primary energy consumption (such as coal, natural gas, etc.). CO_2 emission can be reduced by replacing clean energy sources to renewable energy. This system is able to convert and transfer heat energy from the sun to water, the environment and other absorbers. In addition, this system transfers heat for storage purposes. Had made changes in system conditions, a reduction in the number of system units, costs and an increase in efficiency could have been achieved. There is a sutable platform for doing research on the hybrid systems with different types in different climatic conditions.

Iran is a country that has a great opportunity touse the renewable resources. So,it is easy for the country to produce a significant amount of renewable energy and use it in the industries [9]. Due to repeated heat treatments in the production process, the piping industry emits polluting gases and hazardous wastes that have adverse effects on the environment. To study impact of the pipeline company's inefficient heat pump is the main aim of the present study in which the hot water production system of Ahvaz pipeline company located in the center of Ahvaz was examined as an innovation. Considering the temperature conditions for 12 months, the analysis was based on the effects of the life cycle and equipment exergy destruction on the environment in Ahvaz city . In this regard, environmental exergy analysis wasdone in the area. Through environmental exergy analysis, the thermodynamic inefficiencies of a system can be identified at the component level [10, 11]. Analysis showed that there are peripheral exergy degradation andefficiency for each component.

2. Materials and Methods

As an alternative to electric and natural gas as well as water heaters, the present study investigated the use of indirect expansion of solar-assisted heat pump systems. Solar heat pumps use solar collectors and heat pumps to provide water heating. This setup uses the collector as an evaporator. In solar-assisted heat pump systems, using water or oil-based collectors or a combination of them is not cost-effective because heat exchangers aren't needed. The heat pump and collector use refrigerant in order to work. However, it makes the collector to be rapidly cool. Using this type of collector the solar collector can operate at a temperature that increases the efficiency of solar energy collection, while the heat pump can operate at a temperature that increases the efficiency compared to an air-source heat pump [12]. Figure 1 schematically depicts the cycle using R-134a as the working fluid.

The four main components of a steam compression heat pump cycle are evaporator, expansion valve, condenser, and compressor. The collector is exposed to direct sunlight. The impact of solar-powered energy is engrossed by the liquid refrigeration after hitting the tubes that carry the refrigerant. Heated fluid is transferred to the heat pump by the evaporator. Therefore, in a heat pump, the subcooled liquid is evaporated till steam is saturated in part 1 of procedure 4-1 by constant pressure. Between evaporator and compressive pressures, the refrigerant is compressed in processes 2-3. After heat absorption , the refrigerant is condensed to a saturated liquid under the constant pressure of 3-4. Through

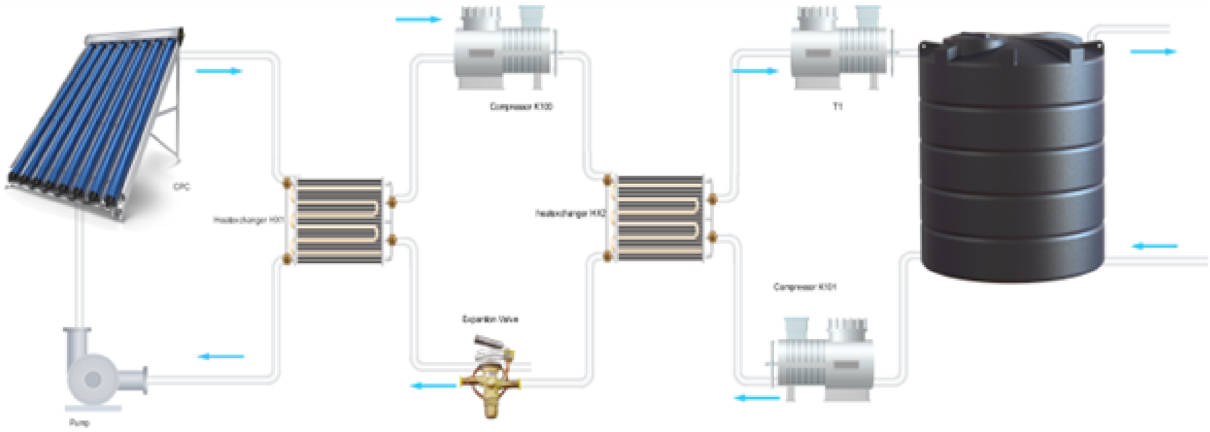

Figure 1. Process of the hot water production system.

this process, the circulating water in the condenser receives latent heat from the condensate. A pressure relief valve is located behind the condenser, which causes the refrigerant to expand. This mixture of liquid and vapor is the result of the process (Figure 1) [13].

The use of heat pumps in manufacturing, refrigeration, and industrial applications has been common for decades [14]. They can be used for heating residentials and commercial areas, cooling and heating water, refrigeration, and many industrial processes [15].

All the information is required for the location where this equipment is installed. First, the collector's temperature at a certain time of a day is considered and the enthalpy values are calculated in the time. Using compressors, collectors, and thermal modules, the average monthly values of the operating compressor, auxiliary and absorbed solar energy are calculated. To estimate the yearly values, the monthy values of these factors are combined for all months [16, 17].

Aspen HYSYS software was used for data analysis, and for accurate mathematical and statistical calculations MATLAB software was used (Table 1). One of the properties of the software is extracting input data from the library of other softwares to perform calculations based on those inputs [18, 19].

Figures 1 and 2 are the process of hot water production system in the solar and the high heat pump of Ahvaz Pipeline Co. This system has three parts. The first part includes a centralized parabolic collector. The second part is a heat pump. The third part is a storage tank. Solar radiation radiates into the centralized parabolic collector and heats the collector ofstreeming fluid. This fluid penetrates into the heat exchanger to transfer the generated heat and the heat from the concentrated parabolic solar which help theoperating fluid to pump the heated fluid. The four main components of a steam compression cycle of heat pump are evaporator, expansion valve, condenser, and compressor. According to the Figures 1 and 2, the storage tank of the city is filled out with water

Figure 2: Solar hot water production system of hot water production system with weather conditions of Ahvaz..

Table 1. Data of solar hot water production system of hot water production system with weather conditions of Ahvaz

Stream Numbers	Temperature (°C)	Pressure (kPa)	Molar Flow (kgmole/h)
1	275	150	589
2	320	400	589
3	89	400	589
4	89	150	589
5	260	90	589
6	90	90	589
7	90	90	589
8	90.	150	589
9	320	50	1980
10	316	30	1980
11	40	30	1980
12	54	50	1980
13	54	50	1980
In	25	100	4425
Out	100	100	4425

and then it leaves after heating. In the analysis by Aspen HYSYS software, Peng-Robinson equations were used.

In the environmental analysis, we performed exergy and LCA analysis for each component of the process and the input entering into the system. The system which was utilized to perform LCA included the supply of input and LCA of the components, especiallythe fuel.

This paper concentrates on the concept of peripheral exergy and the analysis of exergy by combining the two laws of thermodynamics which was previously described [20, 24]. To analyze the results, the following hypotheses have been considered in thermodynamic equations:

a) The reference (dead) state for the system has an ambient pressure of P_0=101.325 kPa and a temperature of T_0=20°C;

b) The system works in a steady state;

c) The exergy balance and energy insignificant changes are seen in gravitational conditions and kinetic;

d) Compressors and pumps are adiabatic;

e) In the heat pump, the refrigerant is saturated at the evaporator outlet and the condenser;

f) Pressure drop is ignored in all pipelines and exchangers heat;

g) There is a steady-state and constant operation;

h) There is adiabatic compressor and capillary tube;

i) Because the connecting pipes are short, heat transfer and refrigerant pressure drop are ignored.

Therefore, it can be concluded that exergy analysis is a fundamental technique to better determine the location, causes, and thermodynamic inefficiency of a process [26, 27]. This analysis is a suitable method to assess the performance of chemical processes, as well [28].

According to Equation 1, the exergy of each current is generally divided into kinetic ($\dot{E}x_{ke}$), potential ($\dot{E}x_{po}$), chemical ($\dot{E}x_{ch}$), and physical ($\dot{E}x_{ph}$) parts [29]. Potential and kinetic exergy can be ignored when the system is at rest relative to its environment [30]. Therefore, the exergy value of each currency can be estimated by Equation 2 [31]:

1. $\dot{E}x = \dot{E}x_{po} + \dot{E}x_{ke} + \dot{E}x_{ph} + \dot{E}x_{ch}$

2. $\dot{E}x = \dot{E}x_{ph} + \dot{E}$

3. $\dot{E}x_{ph} = \dot{m}[(h-h_0) - T_0(S-S_0)]$

In Equations 1-3, the index zero represents the environmental conditions. In Equation 3, ṁ, h_0, s_0, T_0, are mass discharge, enthalpy, entropy and the reference ambient temperature, respectively. Also, in the following equations, Gi and e^0_i are Gibbs free energy and the standard chemical exergy to calculate the chemical exergy, respectively [30-35]. The exergy calculation of currents is shown in detail in Figure 3-5.

One of the most important properties of exergy analysis is that the quality of energy is assessed by introducing the concept of destructed energy in the first law of thermodynamics. The concept, however, enables greater exploitation of energy sources and determination of the exact amount and location of energy lost. The concept also explains the reason for the low efficiency of the system [36].

In the case of two systems in different states, there will be an opportunity for work that will continue as long as these systems are not in equilibrium. So, exergy represents the amount of work that a system can produce until equilibrium is reached [37].

The environment and dead state used to understand exergy analysis. Pressure, chemical composition, and temperature are usually used to determine a dead state. Chemical and physical exergy of a current is calculated using the Equations 4-8 [10, 38].

4. $e^{ph} = (h-h_0) - T_0(S-S_0)$

5. $E^{PH} = \dot{m}e^{PH}$

6. $\dot{E}X_{ch} = \dot{m}ex_{ch} = \dot{m}(\sum x_i e_0 + G - \sum x_i G_i)$

7. $e^{ch} = \sum x_i e_i^{ch,o} + RT^O \sum x_i \ln x_i$

8. $\dot{E}^{CH} = \dot{m}e^{CH}$

The standard chemical exergy of the current components is equal to $e_i^{(ch,o)}$. In the equations, h, s, and o are enthalpies and entropies, respectively [39]. Chemical energy of materials is determined by obtaining the standard amount whose values are not present in the embryones. It is, therefore, appropriate to think of a response that takes into account the standard chemical exergy of all reaction materials in addition to the desired material. Equation 14 is applied to the standard chemical exergy of a given material to obtain the sources [40].

These parameters will determine two important parameters of the process: energy destruction and energy efficiency that should be defined in the analysis using Equations 7 and 8. Also, the exergy returned from the equipment should be defined [27]. These are the basic parameters for the equipment Equations 9 and 10 [21, 23].

9. $\dot{E}x_D = \dot{E}x_F - \dot{E}x_P$

10. $\varepsilon = \frac{\dot{E}x_P}{\dot{E}x_F} = 1 - \frac{\dot{E}x_D}{\dot{E}x_F}$

In the above equations (9-10), the product is shown by index P. The destruction and fuel are also shown using indices D and F, respectively.

The equations for different elements used for the hot water production system equipment are as follows (Equations 11-20):

a) Compressor [41, 42]:

11. $\dot{E}X_D = \dot{E}X_F - \dot{E}X_P = -\sum(\dot{m}.e)_{out} + \sum(\dot{m}.e)_{in} + W$

12. $\varepsilon = \frac{-\sum(\dot{m}.e)_{out} + \sum(\dot{m}.e)_{in}}{W}$

b) Condenser, evaporator and heat exchangers [43].

13. $\dot{E}X_D = \dot{E}X_F - \dot{E}X_P = [\sum(\dot{m}.e)]_{1,(cold)} + [\sum(\dot{m}.e)]_{in,(Hot)} - [\sum(\dot{m}.e)]_{2,(cold)} - [\sum(\dot{m}.e)]_{out,(Hot)}$

14. $\varepsilon = \frac{-[\sum(\dot{m}.e)_{out,(Hot)} + [\sum(\dot{m}.e)]_{in,(Hot)}}{-[\sum(\dot{m}.e)_{1,(cold)} + [\sum(\dot{m}.e)]_{2,(cold)}}$

c) Solar collector [27, 44]:

15. $\dot{E}x_D = \dot{E}x_F - \dot{E}x_P = \sum(\dot{m}.e)_{out} + Q(-\frac{T}{T_0} + 1) + \sum(\dot{m}.e)_{in,}$

16. $\varepsilon = \frac{Q(-\frac{T}{T_0} + 1)}{-\sum(\dot{m}.e)_{out} + \sum(\dot{m}.e)_{in}}$

d) Expansion valve [42, 45]:

17. $\dot{E}x_D = \dot{E}x_F - \dot{E}x_P = \sum(\dot{m}.e)_{in} - \sum(\dot{m}.e)_{out}$

18. $\varepsilon = \frac{e^{\Delta T}_{out} - e^{\Delta T}_{in}}{e^{\Delta P}_{out} - e^{\Delta P}_{in}}$

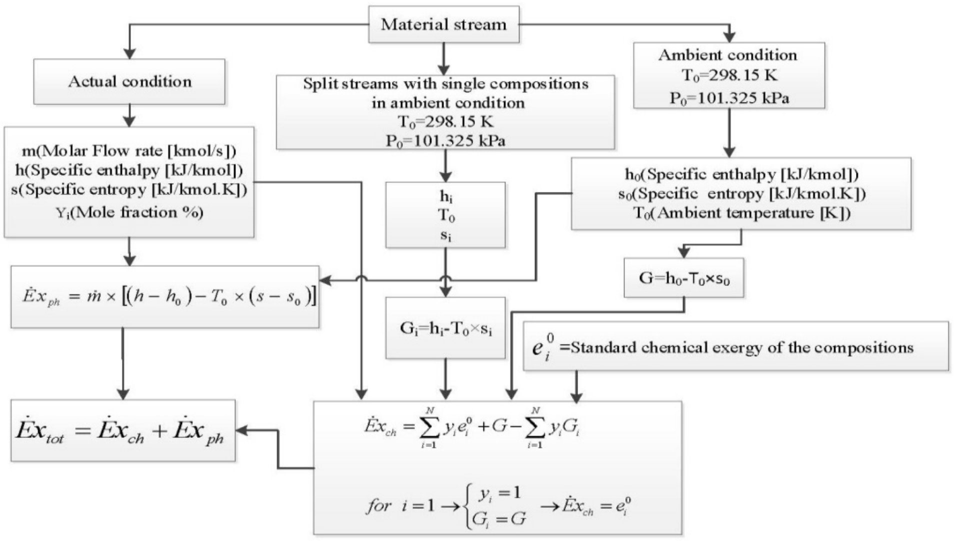

Figure 3. Flowchart of calculating the current exergy

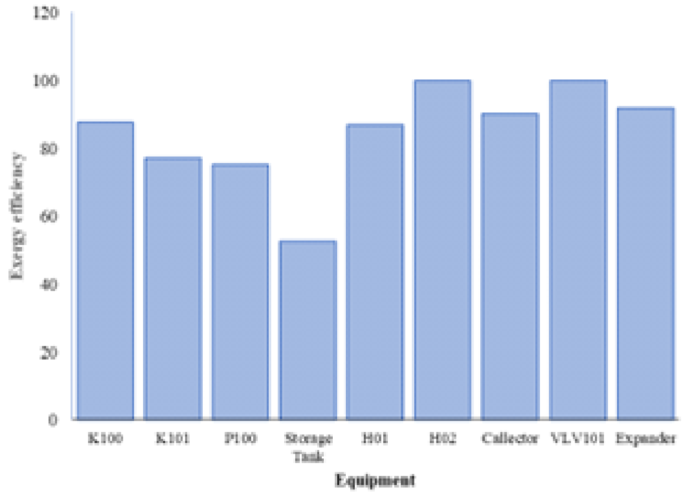

Figure 4. Exergy efficiency of all equipment

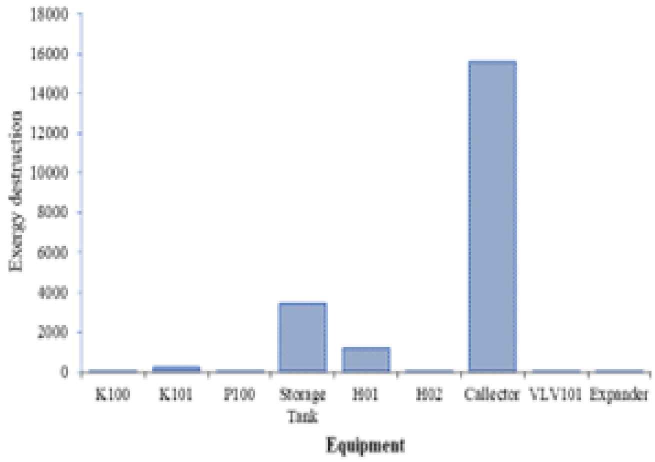

Figure 5 Exergy destruction of all equipment

e) Pump [42, 45]:

19. $\dot{E}X_D=-\dot{E}X_P+\dot{E}X_F=-\sum(\dot{m}.e)_{out}+\sum(\dot{m}.e)_{in}+W$

20. $$\varepsilon=\frac{-\sum(\dot{m}.e)_{out}+\sum(\dot{m}.e)_{in}}{W}$$

$$e^{\Delta T}=[-\int_T^{T_0} dh]\ \frac{T-T_0}{T} \quad e^{\Delta T}=T_0\times(S_0-S_{in})-(h_0-h_{in})$$

Thermal energy is the result of the difference in temperature between the stream and its surroundings when it comes to the expansion valve. The pressure component is also determined by the difference in pressure between the stream and the environment. In this regard, the properties of main currents of the hot water production system are inlet and outlet heat pump water.

An exergy analysis takes into account for the exergy of each k component, the fuel and product which are calculated according to the exergy and economic objectives derived from a specific exergy costing methodology [36]. Estimation of the residuals from exergy variables of a system is possible after calculating fuel and product exergies [46-49].

The three aspects: efficiency, destruction and ratio. The component k's exergetic efficiency is determined by the ratio of the exergy of fuel to the product [50]:

The results of all thermodynamic analyzes based on scientific principles on the processes are presented in the form of defined and known indices or criteria. One of the thermodynamic analysis is energy analysis in which energy consumption is quantitatively studied and its optimality is analyzed [13, 20].

Table 2 shows the results for chemical, physical, and total energy generated by the analysis of currents in MATLAB software. Table 3 shows the results of equipment analysis of exergy.

Overall, efficiency of the energy increases, thereby reducing greenhouse gas emissions (CO_2, NOx, etc). The environmental assessment determines the effect of environmental variables on process performance [51]. This assessment consists of three stages. For each component of the process, a first-stage approach is applied to fuel, exergy assessment, and exergy production as well as exergy destruction rate. In the second stage, we conduct a life cycle assessment to determine the environmental

Table 2. Results of exergy currents

Stream Number	Physical Exergy (kW)	Chemical Exergy (kW)	Total Exergy (kW)
1	8727.85	45669.46	54397/31
2	9377.58	45669.46	55047/31
3	388.42	45669.46	46057/88
4	383.36	45669.46	46052/82
5	8546.15	45669.46	54215/61
6	219.97	45669.46	45889/43
7	397.97	45669.46	46067/43
8	399.55	45669.46	46069/01
9	8000.	359093.50	367093/5
10	6707.47	359093.50	365800/97
11	588.37	359093.50	359681/87
12	175.00	359093.50	359268/5
13	175.02	359093.50	359268/52
In	0.04	297704.52	297704/56
out	3833.30	297704.52	301537/82

Table 3. Results of the equipment analysis exergy

Equipment Number	Exergy Destruction(kW)	Exergy Effieciency (%)
K100	91.74	87.63
K101	225.33	77.10
P100	0.52	75.26
Storage tank	3462.52	52.54
HX1	1180.00	86.90
HX2	3.70	99.96
collector	15563.53	90.11
VLV101	5.05	99.99
expander	106.12	91.78

effects. To perform environmental exergy analysis, the result of exergy analysis is connected to LCA.

A lifecycle assessment is done for each inlet as well as component that enters into the system. Among the processes used to conduct LCA there are inlet and outlet supply, including fuel supply. Following the guidelines of international standard approaches, a primary current inventory (i.e. consumption of natural resources and energy, as well as greenhouse gas emissions) is compiled [52, 53].

So, LCA should be done first. The LCA method is an effective way of to evaluate an activity's environmental impact. Production afects the environment over the life of an energy system, maintenance (O & M), and disposal [54]. It is esential to determine the environmental effect of the product over its lifetime through considering the life cycle of a process. To date, various methods have been proposed and developed to evaluate the environmental effect of thermodynamic systems, namely ReCiPe Endpoint, TRACI 2, CML 2001, and Eco-index 99 [55]. In this study, LCA was performed using the Echo-99 index. According to this index, three types of environmental effects are determined using European aggregated data, including 1) the quality of the ecosystem, 2) the human health; and 3) sources (Table 4) [56]. The life cycle consists of five stages as follows [1]:

1. Materials used for production (per kilogram of materials);

2. The treatment and production process;

3. Material, device, and fuel transportation (per ton-kilometer);

4. Electricity and heat require energy;

5. Waste and materials disposal.

The results are weighted and provided as environmental indicator points (mPts or Pts). The environmental effect is known as "Ecopoint" Pts (1 Pts=1000 mPts), where one point represents 1/1000 of annual environmental losses of an averaged European data [57]. The higher the estimated values, the larger the environmental effect. The results are used to describe the environmental effects of the methods. A person's contribution to each country's environmental effect per year is shown for each product concept. A mill point represents the total score of the effect in terms of a number. This process is estimated for last 25 years [40, 58].

The inlet and outlet valves can be obtained only through considering the functional relationships between the components of the system (i.e. system structur). To formulate a balance between environmental factors and auxiliary equations is necessary. It is recommended that all environmental effects entering into a component should be disposed through the outlet. This is the basis to balance the effects in the system components. Furthermore, the environmental effect of a component's inlet ($\dot{Y}_K$) should be considered as a part of the life-cycle assessment of the component (Equation 21):

21. $$\dot{Y}_K=\dot{Y}_K^{CO}+\dot{Y}_K^{OM}+\dot{Y}_K^{DI}$$

Table 4. Environmental index for equipment [59]

Devices	(mPts/kg)*
Evaporator	86
Condenser	86
Compressor	131
Pump	186
Exchanger Heat	519

*milliPoints per weight

The three stages of construction have different environmental effects, includingproduction, transportation and installation ($\dot{Y}_K^{CO}$). Maintaining and operating, including the generation of pollutants ($\dot{Y}_K^{OM}$) and disposal ($\dot{Y}_K^{DI}$) are the environmental effects associated to the component k ($\dot{Y}_K$). All values of environmental effects are obtained by LCA. Resource consumption and emissions during the operation of the component k which is not related to the system current are dependent on the environmental effect of the operation and maintenance phase ($\dot{Y}_K^{OM}$).

Within each system subunition, the equilibrium of effects on the environment can be expressed as bellow. Table 5 shows ECO indices for the system equipment [60].

The environmental exergy method calculates the environmental effect of k in terms of the environmental effect of energy destruction ($\dot{B}_{kf}$) as well as the$\dot{Y}_k$ These values ($\dot{B}_{kp}$) show the total impact of the component k that is carried by the system which identifies its relevance to the environment (Equation 22):

22. $$\dot{B}_{\dot{K}P}=\dot{Y}_K+\dot{B}_{\dot{K}F}$$

A component's environmental performance is evaluated using external environmental variables [19, 20].

We calculated and defined exergy in an exergy analysis of product-related fuel ($\dot{E}_{F,K}$) and exergy rates ($\dot{E}_{P,K}$). In environmental analysis, we calculated environmental effect rates ($\dot{B}_{P,K}$) and ($\dot{B}_{F,K}$) which are related to fuel and the product of k. The average of environmental effects (exergy-based) of fuel and product k is is estimated by Equations 23 and 24) [61]:

23. $$b_{P,K}=\frac{\dot{B}_{P,K}}{\dot{E}_{P,K}}$$

24. $$b_{F,K}=\frac{\dot{B}_{F,K}}{\dot{E}_{F,K}}$$

Position and relationship between components k affect the values of ($b_{F,k}$) and ($b_{P,k}$). The components which are close to the fuel in the system tend to have lower values, whereas components near the system's product current tend to have higher values. As a result, the rate of exergy is reduced and the rate of environmental effect increases since we move from the fuel of the system to its product (Equation 25) [61].

25. $$\dot{B}_{D,K}=b_{F,K}\,\dot{E}_{D,K} \qquad if\,\dot{E}_{D,K}=Conts$$

Table 5. Environmental indices for different materials [61]

Indicator 99 (mPts/kg) for Material Eco-indicators	Indicator 99 in mPts/kg
Aluminum	780
Copper	1400
Iron cast	240
Stainless steel	86
High alloy steel	910
Low alloy steel	110

Table 6. Results of exergy in fuel, product and destruction of hot water production system with weather conditions of Ahvaz

Equipment Number	$\dot{E}_{Fuel}$	$\dot{E}_{Product}$	$\dot{E}_{Dest}$
K100	$\dot{E}_f=\dot{E}_{w\_K100}$	$\dot{E}_P=\dot{E}_2-\dot{E}_1$	$\dot{E}_D=\dot{E}_{w\_K100}-\dot{E}_2+\dot{E}_1$
K101	$\dot{E}_f=\dot{E}_{w\_K101}$	$\dot{E}_P=\dot{E}_{12}-\dot{E}_{11}$	$\dot{E}_D=\dot{E}_{w\_K101}-\dot{E}_{12}+\dot{E}_{11}$
P100	$\dot{E}_f=\dot{E}_{\dot{w}\_P100}$	$\dot{E}_P=\dot{E}_7-\dot{E}_6$	$\dot{E}_D=\dot{E}_{\dot{w}\_P100}-\dot{E}_7+\dot{E}_6$
Storage tank	$\dot{E}_f=\dot{E}_{10}-\dot{E}_{11}$	$\dot{E}_P=\dot{E}_{out}-\dot{E}_{in}$	$\dot{E}_D=\dot{E}_{10}+\dot{E}_{in}-\dot{E}_{11}-\dot{E}_{out}$
HX1	$\dot{E}_f=\dot{E}_{12}-\dot{E}_9$	$\dot{E}_P=\dot{E}_3-\dot{E}_2$	$\dot{E}_D=\dot{E}_{12}+\dot{E}_2-\dot{E}_3-\dot{E}_9$
HX2	$\dot{E}_f=\dot{E}_5-\dot{E}_6$	$\dot{E}_P=\dot{E}_1-\dot{E}_4$	$\dot{E}_D=\dot{E}_5+\dot{E}_4-\dot{E}_6-\dot{E}_1$
Collector	$\dot{E}_f=\dot{E}_{Q\text{-}Coll}$	$\dot{E}_P=\dot{E}_5-\dot{E}_7$	$\dot{E}_D=\dot{E}_{Q\text{-}Coll}+\dot{E}_7-\dot{E}_5$
VLV101	$\dot{E}_f=\dot{E}_3$	$\dot{E}_P=\dot{E}_4$	$\dot{E}_D=\dot{E}_F+\dot{E}_P$

The exergy destruction is assumed to be compensated by consuming more fuel to achieve the same amount of product ($\dot{E}_{P,K}$). Therefore, the mean environmental effect ($b_{F,k}$) is multiplied by the rate of exergy destruction ($\dot{E}_{D,K}$) associated with a given component fuel. The rate of environmental effect associated with the exertion of destruction on a component should not be determined through fuel-specific environmental effects. In this regard, a specific environmental impact of the fuel component k is used. Consequently, the relative position of a component in the system affects the environmental effects of energy destruction ($\dot{B}_{D,K}$). Energy destruction is governed by the average specific environmental effect ($b_{F,k}$), According to its relative position in the system, component k determines how the system behaves.

There are still more unmeasured factors in these equations than relationships. Therefore, an auxiliary equation based on the fuel derived from each device and the exergy rate of each product have been used to solve this problem. Based on environmental equilibria and auxiliary equations, the linear matrix is formed as below (Equation 26) [62]:

$$26.\ [\dot{E}_K]\times[b_K]=[\dot{Y}_K]$$

Where b_k and $\dot{Y}_k$ represent the unit of environmental effect vector and the environmental effect of the component k, respectively. Using an environmental approach, the effects associated with components k are calculated by estimating the environmental effects of exergy destruction ($\dot{B}_{D,K}$) and the component.

Given the environmental approach, the total environmental effects of the component k are calculated by the exergy destruction effect ($\dot{B}_{D,K}$) and its combination with the componen $\dot{Y}_k$. By combining these values ($\dot{B}_{TOT,k}$) we can identify the overall environmental effect of the component k and its relevance to the studied system (Equation 27) [62]:

$$27.\ \dot{B}_{TOT,K}=\dot{Y}_K+\dot{B}_{D,K}$$

In terms of relative differences $r_{(b,k)}$, the following equation is typical of the fuel $b_{(F,k)}$ and the mean environmental effects of the product $b_{(P,k)}$ (Equation 28) [62]:

$$28.\ r_{b,k}=\frac{b_{P,K}-b_{F,K}}{b_{F,K}}$$

A component's ability to reduce the environmental effects is indicated by the above environmental variable. In general, a high $r_{b,k}$ value suggests that the environmental effect of a larger component can be reduced more easily than a smaller component. According to the relative difference between specific environmental effects and their absolute values, the environmental quality of a component is indicated.

The relative contribution of environmental effects originating from a component to the sum of environmental effects originating from the component k is estimated by $f_{b,k}$. The factor shows size of environmental effect of component on the sum of all the effects (Equation 29) [47, 58, 62]:

$$29.\ f_{b,k}=\frac{\dot{Y}_K}{\dot{Y}_K+\dot{B}_{D,K}}=\frac{\dot{Y}_K}{\dot{B}_{TOT,K}}$$

Table 7. Exergy results of the main equipment of the hot water production system of Ahvaz Pipeline Co.

Equipment Number	Exergy Destruction(kW)	Exergy Effieciency(%)
K100	91.74295857	87.62693498
K101	225.3341818	77.093451
P100	0.518750786	75.25789389
Storage tank	3462.515429	52.54126483
HX1	1180.008333	86.90212414
HX2	3.696719122	99.95582409
collector	15563.5317	90.10980984
VLV101	5.054417379	99.98900207
expander	106.1198845	91.78449342

Table 8. Environmental indices in the cycle of heat pump equipment of hot water production.

Component	Material Composition	Amount	Process mPts/kg	Material mPts/kg	Disposal mPts/kg	Total mPts/kg
Exchangers of heat [1] Storage Tank	Copper Stainless steel	33% 67%	12.1	519	−70	461.1
Collector [1]	Stainless steel	100%	12.1	86	−70	28.1
Pump [1]	Stainless steel The iron cast	35% 65%	16.9	186	−70	132.9
Compressor [2] Turbo Expander	Stainless steel The iron cast The low alloy steel	33.33% 86 22.22% 240 44.5% 110	11.7	130	-70	71.7

Table 9. Environmental effect

Equipment Number	Wquipment Weight (kg)	Evironmental Impacts (mpts)	Evironmental Impact Rate (mpts/hr)
W-P100	654.5504	132.9	0.476656
T2	58693.4	71.7	23.05927
storage tank	139343.5	461.1	352.0618
E-100	14424.23	461.1	36.44389
HX2	725202.9	461.1	1832.28
K-101	68492.39	71.7	26.90907
P-100	249.4756	132.9	0.181673
HX1	831101.7	461.1	2099.841
K-100	12023.01	71.7	4.723561

Table 10. The result of exergy analysis of the processing equipment.

Equipment Number	Main Equation	Auxiliary Equation
HX1	$\dot{E}_{12}b_{12}+\dot{E}_{2}b_{2}+\dot{Y}_{HX-1}=\dot{E}_{9}b_{9}+\dot{E}_{3}b_{3}$	$b_{12}=b_{9}$
HX2	$\dot{E}_{5}b_{5}+\dot{E}_{4}b_{4}+\dot{Y}_{HX-2}=\dot{E}_{6}b_{6}+\dot{E}_{1}b_{1}$	$b_{5}=b_{6}$
storage tank	$\dot{E}_{10}b_{10}+\dot{E}_{in}b_{in}+\dot{Y}_{Storage\_Tank}=\dot{E}_{11}b_{11}+\dot{E}_{out}b_{out}$	$b_{10}=b_{11}$
P-100	$\dot{E}_{\dot{w}\_P100}b_{\dot{w}\_P100}+\dot{E}_{6}b_{6}+\dot{Y}_{\dot{w}\_P100}=\dot{E}_{1}b_{1}$	b_{w-P100}=6206 (mPts/GJ)
K-100	$\dot{E}_{W\_K100}b_{W\_K100}+\dot{E}_{1}b_{1}+\dot{Y}_{W\_K100}=\dot{E}_{2}b_{2}$	b_{W_K100}=6206 (mPts/GJ)
K-101	$\dot{E}_{W\_K101}b_{W\_K101}+\dot{E}_{11}b_{11}+\dot{Y}_{W\_K101}=\dot{E}_{12}b_{12}$	b_{W_K101}=6206 (mPts/GJ)
VLV-101	$\dot{E}_{3}b_{3}=\dot{E}_{4}b_{4}$	
Collector	$\dot{E}_{8}b_{8}+\dot{E}_{Q\text{-}Collector}b_{Q\text{-}Collector}+\dot{Y}_{Q\text{-}Collector}=\dot{E}_{5}b_{5}$	$b_{Collector}$=5320 (mPts/GJ)
	$\dot{E}_{T2}b_{T2}+\dot{E}_{9}b_{9}+\dot{Y}_{T2}=\dot{E}_{10}b_{10}$	b_{W_T2}=6206 (mPts/GJ)

Table 11. Results of current output based on ecological exergy.

Equipment Number	(kW)	b(mPts/GJ)	(mPts/h)
01	1973412.927	10092	54317.30653
02	1756988.349	8879	54967.03675
03	21839.18397	132	45957.87873
04	1612944.133	9750	45952.82431
05	2331723.855	11960	54155.60792
06	1971423.543	11960	45787.42899
09	65277153.96	49395	367092.6767
10	15930339.79	12097	365800.9744
11	15612611.61	12097	358505.1301
12	63884955.27	49395	359263.5066
b collector	141282.9634	5320	7376.93
Wk101	21977.43192	6206	983.7
Wk100	16566.2964	6206	741.5
WP	46.8503352	6206	2.097
in	157545.215	147	297704.488
out	430957.8479	397	301537.8169
W-T2	26497.1376	6206	1186

3. Results and Discussion

In this project, a cycle process of solar heat pump was modeled by Aspen HYSYS and assessed exergetically and ecologically. The objective was to assess the thermal and environmental advantages as well as identify inefficient equipment. The relationship between thermodynamics and the energy conversion system showed the environmental effects of each component of the system as well as the actual sources. Therefore, the approaches in this study suggest that an accurate integrated assessment of the energy conversion system from the perspective of thermodynamics and environmental protection can be addressed.

Thermodynamic performance of a system is very useful indicator for the system assessment. Because is reveals the component which causes some parts or all components of exergy destruction. This data is obtained from theoretical, actual process, synthetic and unavoidable processes that should be taken into account. The results are as following (Table 6 and 7).

Indices of environmental effects from LCA have been shown in Table 8. They are based on the material used in heat pump equipment of the hot water production. In this regard, in order to calculate the environmental effect of this equipment, it is necessary to determine the weight of each equipment. The equipment weight values were obtained by the Aspen HYSYS software that have been presented in Table 9. In order to determine the environmental impact rate, this equipment had a shelf life of 25 years with operating hours of 7300 hours, including annual repairs.

The environmental effect of the equipment in terms of weight was investigated. According to the table, HX1 heat exchanger had the highest rate of environmental effect due to the heaviest equipment.

The next critical parameters in each cycle are the equipment that produce or consume the work. Using the Equation 22, the main auxiliary equations for the hot water production system in the factory were produced (Table 10). Electricity and heat have been shown in this table which are equal to 6206 and 5320 mpts/GJ, respectively. Table 11 shows the environmental effects of cycle currents of plant hot water production. Almost all of the environmental effects were due to current No. 9 and exergy rate of B.

According to Table 12, f_b of K101 equipment is higher than other system equipment, indicating that LCA, including the compressor material, shelf life and annual operating hours should be addressed. Also, f_b of solar collector equipment was less than other equipment, which indicates that it has the greatest environmental impact due to its energy destruction. In addition, the high rate of r_b in this equipment indicates its potential role for improving environmental effect of the equipment.

4. Conclusion

The hot water production system of Ahvaz Pipeline Co. was investigated from the perspective of overall and environmental exergy. The most exergy destruction of current No. 2 was associated to the solar collector equipment (15563/53175). Also, energy efficiency was the lowest in the storage tank (52.54%). From the perspective of CLA

Table 12. Results of system ecological assessment.

Equipment Number	Exergy Destruction(kW)	(mPts/h)	(mPts/h)	(mPts/GJ)	(mPts/GJ)	(mPts/h)	(%)	(%)
K100	91.74295857	0.476656	209831.4	53499.55	49395	209831.8767	8.309642	0.100227161
K101	225.3341818	1832.28	159.1659	11970.88	11960	1991.4459	0.090977	92.00751794
P100	0.518750786	352.0618	150789.8	19812.53	12097	151141.8618	63.78055	0.232934679
Storage tank	3462.515429	0.181673	11.58972	767401.8	6206	11.771393	12265.48	1.54334222
HX1	1180.008333	4.723561	2049.684	49561.37	6206	2054.407561	698.604	0.229923196
HX2	3.696719122	26.90907	5034.326	13661.49	6206	5061.23507	120.1336	0.531669931
Collector	15563.5317	36.44389	298072.8	2247811	5320	298109.2439	42152.09	0.012225014
VLV101	5.054417379	23.05927	2370.888	10611925	6206	2393.94727	170894.6	0.963232189
Expander	106.1198845	0.476656	209831.4	53499.55	49395	209831.8767	8.309642	0.100227161

and impact of energy destruction as well as energy efficiency on the environment, , we observed that f_b of the solar collector had the highest value among other equipments, indicating that it has the greatest environmental impact. Compressor K101 should also be reviewed for CLA due to the high percentage of environmental factor.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

All authors equally contributed to prepare this project.

Conflict of interest

The authors declared no conflict of interest.

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$$\dot{E}_{12}b_{12}+\dot{E}_{2}b_{2}+Y_{HX\text{-}1}=\dot{E}_{9}b_{9}+\dot{E}_{3}b_{3}$$

Further Information:

Nomenclature	
$\dot{Y}_K$	Component-related environmental impacts (mPts/h)
$\dot{Y}_K^{CO}$	Environmental impacts related to production, transportation and installation (mPts/h)
$\dot{Y}_K^{DI}$	Environmental effects related to the excretion component (mPts/h)
$\dot{Y}_K^{OM}$	Environmental effects related to Maintaining and operating (including pollution formation (mPts/h)
$\dot{B}$	Exergy's impact rate on the environment (mPts/h)
$\dot{E}_x$	Rate of exergy (kW)
$\dot{m}$	Flow rate in mass (KJ/Kg)
e^0_i	Standard chemical exergy
b	Environment-related impact of units (mPts/GJ)
f_b	Exergoenvironmental factor (%)
r_b	Relative environmental impacts difference (%)
e	Exergy specifics (kJ/kgmol)
E	The rate of emission
Gi	Energy from Gibbs (kJ/kgmol)
h	Enthalpy specific (kJ/kg)
Q	Heat Task (kW)
T	Temp (K)
W	Ability (kW)
s	Entropy (kJ/K)
ε	Exergy efficiency (%)
τ	Annual operating hours (h)

Subscripts	
D	Exergy destruction
P	the product
F	Fuel
0	Dead state
in	Entrance
out	Output
po	Potential
ph	Physical
ch	Chemical
ke	Kinetic
tot	Total
F	Fuel
P	product
ex	Exergy

Device	Name
VLV-101	expansion valve
Storage tank	Reservoir
HX2	Heat exchanger
K-101	Compressor
P-100	pump
HX1	Heat exchanger
K-100	Compressor