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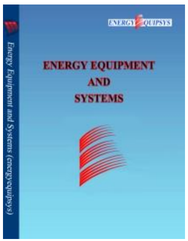

The development and assessment of solar-driven Tri-generation system energy and optimization of criteria comparison

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ABSTRACT

In this research, the thermodynamic investigation of the tri-generation system is performed by the first and second law of Thermodynamics. The trigeneration system under study consists of three subsystems including the solar subsystem, Kalina subsystem and lithium bromide-water absorption chiller subsystem. The proposed system generates power, cooling and hot water using solar energy. The system considered is designed and evaluated based on the climate condition in Zahedan, Iran. The calculation results show that the most exergy destruction rate takes place in the solar cycle. The assessment of system is used dynamic and static forms. In dynamic form, that maximum total cost rate, energy and exergy efficiency are equal to 15.1 dollars per hour,by 33% and 36.47%, respectively. The results base-case demonstrate that energy and exergy efficiencies and total cost rates are equal to 9.63 dollars per hour by 17.37% and 18.82% , respectively in static analysis. Furthermore, optimization criteria comparison such as energy efficiency, exergy efficiency and power are discussed in static form. The results of static evaluation revealed that the power is the best criteria for thermodynamics. Moreover, optimization results based on maximum power criterion show that produced power, energy efficiency, exergy efficiency and total cost rate increase by 28%, 12.32%, of 13.97% and 7.68%, respectively in comparison with the base case.

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1. Introduction

Sustainable Development is defined as a human development mode that uses energy sources conditionally so that it does not have an undesirable effect on the environment and future generation needs. The relationship between energy, the environment and sustainable development is similar to the three vertices of a triangle [1]. Therefore, the balance between energy, the environment, and sustainable development must be preserved. Presently, most production power of societies is supplied by fossil fuels such as coal and natural gas, while these fuels are polluted the environment. On the other hand, renewable energy such as solar energy, geothermal energy, biomass and wind energy are clean energies. The energy crisis and the pollution of fossil fuels show the growing importance of renewable energies. This pollution causes extreme weather, global warming, and

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ecosystem changes. The continuation of these conditions are gradually caused to earth to be uninhabitable for humans. The prediction of carbon dioxide production in the world suggests that environmental pollution will increase in the future, which threatens the health of humans and other living organisms [2]. Among renewable energies, solar energy is even more important for researchers because the solar potential and exergy of the solar radiation are very high. However, using solar energy has also problems such as high cost, low received solar radiation efficiency, high optical losses, and thermal losses. In addition, climate change leads discontinuities in solar radiation. There are many renewable energy projects in comprehensive plans such as the United States, China, and etc. [3].

The storage of thermal energy has been affected by modern technologies. The discontinuity of solar radiation has caused to have required saving energy by solar systems, specifically, when the solar radiation is low, for example at night and in cloudy days. Usually, thermal energy storage (TES) is used to reduce initial costs and operational costs [4].

Recently, researchers have produced purposes such as hot water, hydrogen and fresh water from the primary source of energy. They have gone beyond single generation system, they have been able to produce more than one purpose using the waste of energy. Ahmadi and Dincer [5] performed the exergoenvironmental analysis and optimization of cogeneration system that produced 50 MW of electricity and 33.3 kg/s of saturated vapor at a pressure of 1.3 bar. In their research, they presented a new objective function that included operational cost, fuel cost and environmental parameters such as the cost of pollutant. They calculated the minimum of the objective function by the genetic algorithm. They demonstrated the increase in fuel costs lead to increase in isentropic compressor efficiency, isentropic turbine efficiency and turbine input temperatures. Ahmadi et al. [6] modeled a trigeneration system that produced cooling, heating and power. The trigeneration system consists of a gas turbine cycle, a Rankine cycle, a single effect absorption chiller and a domestic water heater. Also, the parametric study results showed that compressor pressure ratio, inlet gas turbine temperature and isentropic gas turbine efficiency has significantly effect on exergy efficiency and environmental effects of the system. Khaliq [7] investigated a multigeneration system with production cooling, heating and power. They showed that exergy destruction in combustion chamber and heat recovery steam generation (HRSG) are significantly affected by overall pressure ratio and inlet turbine temperature. Ahmadi et al. [8] studied a trigeneration system with thermodynamic purposes such as cooling, heating and electricity. The trigeneration system consists of a gas turbine cycle, a steam turbine cycle and a single effect absorption chiller. Consequently, trigeneration and cogeneration systems are considered as a way to increase the system efficiency and reduce irreversibility.

Kalina cycle is a thermodynamic cycle that uses the ammonia-water mixture as the working fluid. A better feature of the ammonia-water mixture is matched to thermal source compared to pure water [9]. Wall et al. [10] studied the Kalina cycle from the perspective of exergy. They proved that the efficiency of the Kalina cycle is optimized by 10% more than the Rankine cycle. Wang et al. [11] evaluated the Kalina cycle that used solar energy. They used a thermal storage system to ensure system stability. They proved that thermal storage system provides thermal energy when solar radiation is not sufficient.

Absorption chiller produces Cooling from an independent heat source or from the waste heat of other cycles like the solar cycle, Rankine cycle and Brayton cycle. Chua et al. [12] modeled an irreversible absorption chiller. Thermodynamics analysis and describing the absorption chiller process were studied based on Colburn–Drew Equations. Also, the assessment of the effect of different system on absorption chiller performance was irreversibility carried out by general macroscopic Equation. Farshi et al [13] analyzed the exergy-economics of three classes of double effect lithium-bromide and water refrigeration system, in order to evaluate overall systems and product cost flow rates. Their results are helpful in choosing, designing and improving lithium-bromide and water based on refrigeration systems in demonstrating the advantages and disadvantages of the two lithium-bromide absorber properties and water economically.

The current study has the perspective of sustainable development by minimizing the cost and increasing the production power of renewable energy. This research has implemented the concepts of thermodynamics for the analysis of a trigeneration system with producing cooling, heating and power. The novelty of this research is power analysis and its comparison with classical thermodynamic analysis such as energy and exergy efficiencies analysis. Another innovation in this study is to use Kalina cycle instead of the Rankine cycle.

Nomenclature

A_a	Aperture area, m^2
A_r	Received area , m^2
F'	Collector efficiency factor
F_R	Heat removal factor
$\dot{Q}$	Heat transfer rate, kW
T_a	Ambient temperature, K
T_f	Inlet collector temperature, K
T_s	Thermal Storage Temperature, K
$\dot{m}$	Mass flow rate, Kg/s
A	Area, m^2
h	Specific enthalpy, kJ/kg , Heat transfer coefficient, kW/m^2K
D	Diameter, m
G	Solar radiation rate, W/m^2
K	Thermal conductivity coefficient, KW/m^2K
L	Length, m
U	Heat transfer coefficient, kW/m^2K
Z	Purchase cost, $\$$

Subscripts

abs	Absorption
ap	Aperture
con	Condenser
dwh	Domestic water heater
i	Inlet
kc	Kalina cycle
state numbers	1…50

Greek letters

α	Absorptivity
η	Efficiency
ξ	Insulation thickness, m
ρ	Specular reflectance of the concentrator
τ	Effect of angle of incidence

2.System description

The schematic of the trigeneration system has been presented in Fig. 3. The system under study consists of three subsystems. The first subsystem is the solar cycle. Solar energy is received by parabolic trough collectors, Optical and thermal losses, reduce the amount of heat transfer down to the heat transfer fluid. The heat transfer fluid is the Therminol-66. thermal storage is used to ensure the uniformity of the heat source. When the amount of solar radiation is reduced, for example at night and cloudy days, thermal storage supplies the energy required to operate the system. The second subsystem is lithium bromide and water absorption chiller that provides heat from the solar cycle. The studied system is evaluated based on weather conditions in Zahedan. Figure1 presents average ambient temperature in this period. Input data of the studied system is tabulated in Table 1.

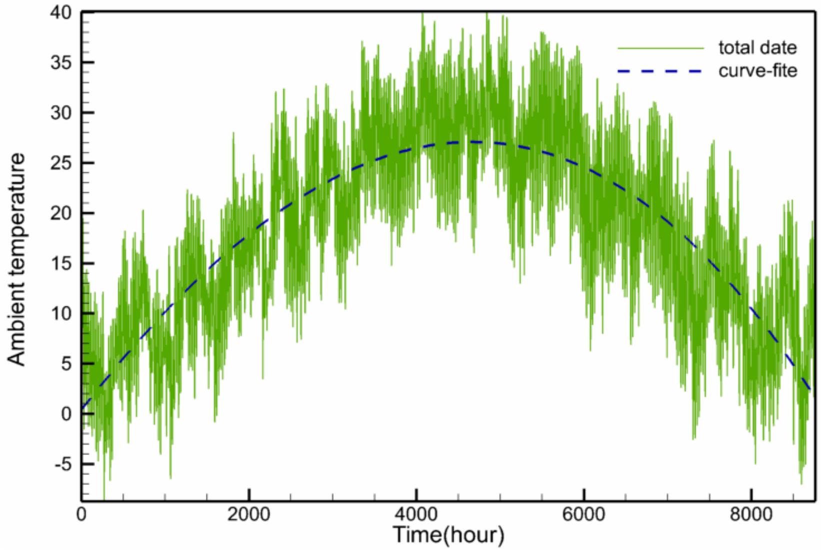

Fig. 1. Variation ambient temperature in Zahedan

Table 1. Input date trigeneration system

Parabolic trough solar collectors	
Collector type	LS-3
Heat transfer fluid	Therminol -66
Absorption chiller	
Absorption Chiller Evaporator Temperature (℃)	1.5
Absorption chiller generator Temperature (℃)	89.4
Absorption chiller absorption temperature(℃)	32.9
Absorption chiller condenser temperature(℃)	39.9
Kalina cycle	
Working fluid	Ammonia-water
Ammonia concentration(%)	20

In fact, solar radiation is variable in the solar system. as a result, solar system analysis is a dynamic analysis. The complexity of dynamic analysis leads to use average by researchers over a long period of time. Average solar radiation is used as input date [16, 17]. variation average solar radiation in Zahedan has been shown in Fig. 2.

3. Energy and exergy analysis

Energy consists of the sum of anergy and exergy. Anergy is defined as waste energy and exergy based on the maximum work; in other words, useful energy. Thermodynamic systems are evaluated based on energy conservation and also exergy balance, according to the first and second law of thermodynamics, respectively [14].

3.1 Parabolic trough solar collector

Parabolic trough collectors are high-temperature and concentrating collectors. These collectors have a temperature range of 60 - 400°C and concentration ratio of 10 - 85 and also a tube absorber. The useful collector heat is written as follows [15]:

$$Q_u = F_R A_a \left[S - (A_r/A_a) U_L (T_f - T_a)\right] \quad (1)$$

In Eq.(1), T_f is the inlet collector temperature. The average solar radiation in Zahedan city, the Islamic Republic of Iran in a period of 10 years (2006-2016) is equal to 386 W/m^2. The absorbed solar radiation in the collector is obtained as follows:

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

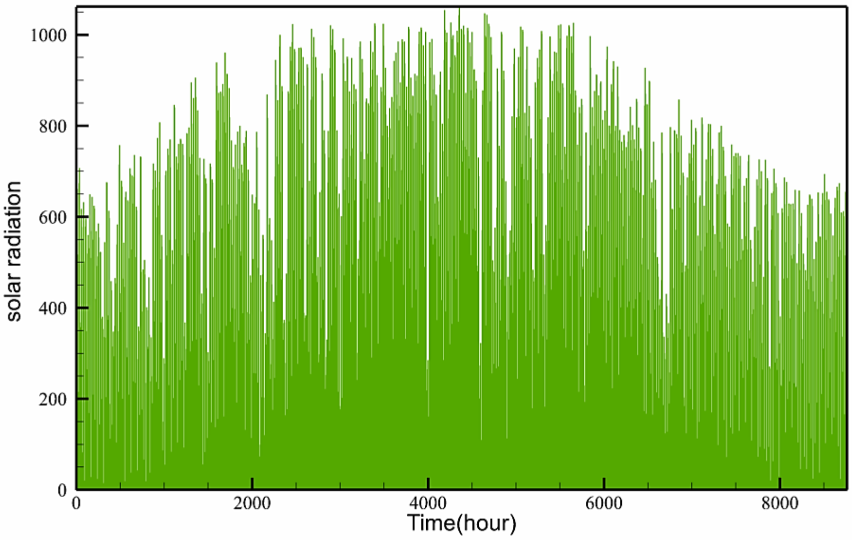

Fig.2. Variation average solar radiation in Zahedan

In Eq.(2), I_{ap} is the received radiation measured on the plane of the aperture, τ is transmissivity of the concentrator, ρ is the reflection coefficient of the concentrator, and α is the absorptivity of the concentrator. The absorber tube area is calculated as follows:

$$A_r = \pi D_o L \tag{3}$$

In Eq.(3), D_o is the outer absorber diameter and L is length of the collector.

The collector aperture area is calculated as follows:

$$A_a = (w - D)L \tag{4}$$

In Eq.(4) w is an aperture and D is the outer absorber cover diameter.

So, the heat removal factor is calculated as follows [16]:

$$F_R = (\dot{m}_{sc}\, c_p/A_r U_L)\,(1 - \exp(A_r U_L\, F'/\dot{m}\, c_p)) \tag{5}$$

In Eq.(5), c_p is the thermal capacity of the heat transfer fluid, $\dot{m}_{HTF}$ is the mass flow rate of the heat transfer fluid, U_L is the total heat transfer coefficient, A_r is the absorber area, and F' is the thermal efficiency factor. The thermal efficiency factor is defined as:

$$F' = (1/U_L)/(1/U_L + D_o/H_{te}\, D_i + D_o/2k + \ln(D_o/D_i)) \tag{6}$$

In Eq.(6), H_{te} is the coefficient of heat transfer on the inner surface of the tube, D_i is the absorber inner diameter, and k is conductivity of absorber tube [18-21].

3.2 Thermal storage

Variable and unpredictable of solar radiation is an implementation problem of solar systems. Accordingly, the usage of thermal storage is essential in solar systems. The energy balance for the storage tank is written as follows:

$$Q_s = Q_{sc} - Q_{loading} - Q_l \tag{7}$$

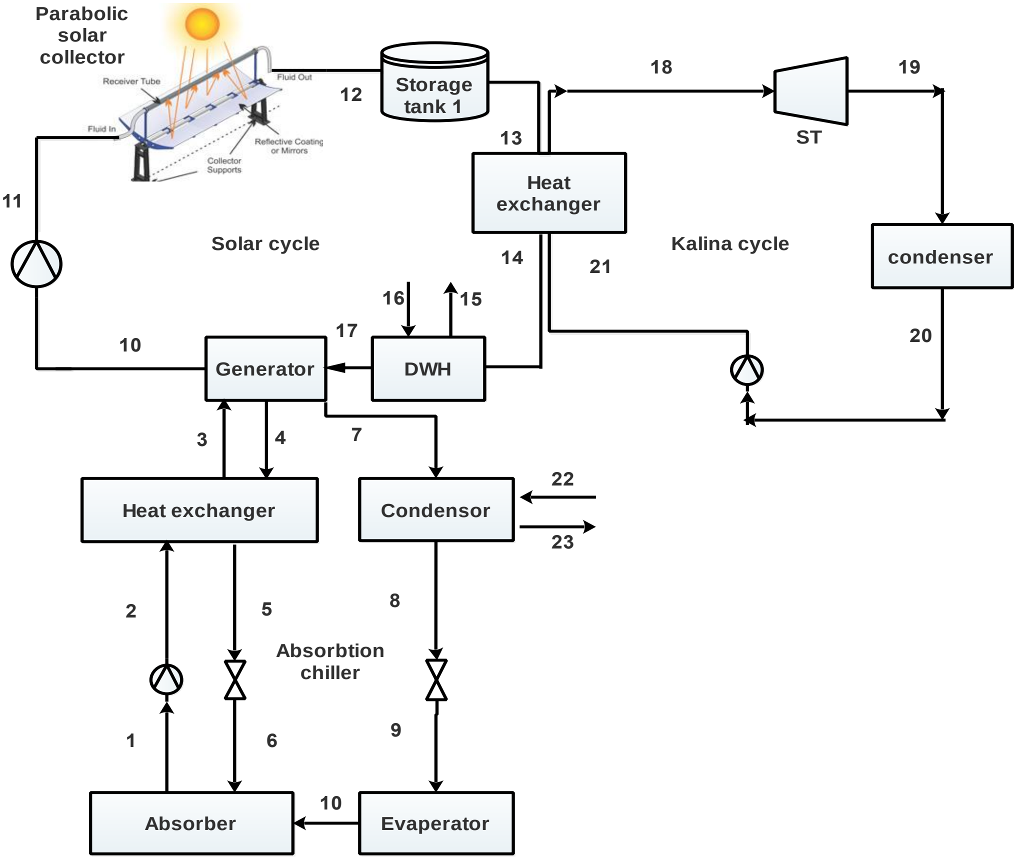

Fig. 3. Schematic of trigeneration system for the provision of heating, cooling and hot water

In Eq.(7), Q_s is the heat stored in the tank, Q_{sc} and $Q_{loading}$ are the rates of addition or removal of energy from the collector, and Q_l is tank heat losses. The energy stored in the tank is expressed as follows:

$$Q_s = Mc_p dT_s/dt \tag{8}$$

where in T_s is thermal storage temperature. The heat transfer coefficient U between the air and fluid is calculated as follows:

$$1/UA = 1/hA + \xi/kA \tag{9}$$

where in ξ is the insulation thickness and k is the thermal conductivity. $\dot{Q}_l$ can be found using the following Eq.(10).

$$\dot{Q}_{tl} = UA(T_\mathrm{i} - T_0) \tag{10}$$

In the Eq.(10), T_i is inlet HTF temperature in thermal storage and T_0 is the ambient temperature [15, 22-24].

3.3 Domestic water heater

The heat transfer fluid passes through the boiler and enters the domestic water heater, and the water is heated up to 60°C. The energy balance of the domestic water heater is written as follows:

$$\dot{Q}_{dwh} = \dot{m}_{sc}(h_{30} - h_{17}) = \dot{m}_w(h_{32} - h_{31}) \tag{11}$$

where in $\dot{m}_{sc}$ is mass flow rate of the solar cycle.

3.4 Boiler

The boiler is part of the system that transfers heat from the solar cycle to the Kalina cycle. In this paper, the boiler is a heat exchanger between the solar cycle and Kalina.

$$\dot{Q}_{boiler} = UA(T_{13} - T_{14}) \tag{12}$$

U is the total heat transfer coefficient and A is the surface boiler.

3.5 Absorption chiller generator

The Absorption chiller generator is the required heat from the solar cycle. The heat transmitted to the generator is calculated using the following Eq.(13):

$$\dot{Q}_{gen} = \dot{m}_{sc}(h_{17} - h_{10}) \tag{13}$$

Therefore, the energy balance for the generator can be written as follows:

$$\dot{m}_3 h_3 + \dot{Q}_{gen} = \dot{m}_4 h_4 + \dot{m}_7 h_7 \tag{14}$$

The destruction exergy for the generator is calculated as follows:

$$\dot{Ex}_{d,gen} = \dot{Ex}_3 + \dot{Ex}_{gen} - \dot{Ex}_4 - \dot{Ex}_7 \tag{15}$$

$$\dot{Ex}_{gen} = (1 - T_0/T_{gen})\dot{Q}_{gen} \tag{16}$$

$$\dot{Ex}_3 = \dot{m}_3(h_3 - h_0) - T_0(S_3 - S_0) \tag{17}$$

$$\dot{Ex}_4 = \dot{m}_4(h_4 - h_0) - T_0(S_4 - S_0) \tag{18}$$

$$\dot{Ex}_7 = \dot{m}_7(h_7 - h_0) - T_0(S_7 - S_0) \tag{19}$$

3.6 Absorption chiller heat exchanger

The mass balance for the absorption chiller heat exchanger is expressed as follows:

$$\dot{m}_2 = \dot{m}_3 \tag{20}$$

$$\dot{m}_4 = \dot{m}_5 \tag{21}$$

The energy and exergy balance for the heat exchanger of absorption chiller are calculated as follows:

$$\dot{m}_4(h_4 - h_5) = \dot{m}_2(h_3 - h_2) \tag{22}$$

$$\dot{Ex}_{d,hex} = \dot{m}_4(\dot{Ex}_4 - \dot{Ex}_5) - \dot{m}_2(\dot{Ex}_3 - \dot{Ex}_2) \tag{23}$$

3.7 Absorption chiller condenser

The mass balance equation for the adsorption chiller condenser is obtained as follows:

$$\dot{m}_7 = \dot{m}_8 \tag{24}$$

$$\dot{m}_8 h_8 + \dot{Q}_{con} = \dot{m}_7 h_7 \tag{25}$$

The exergy balance for the adsorption chiller condenser is calculated as follows:

$$\dot{Ex}_{d,con} = \dot{m}_7(\dot{Ex}_7 - \dot{Ex}_8) - (1 - T_0/T_{con})\dot{Q}_{con} \tag{26}$$

3.8 Absorption chiller evaporator

The mass balance for the absorption chiller evaporator is written as follows:

$$\dot{m}_9 = \dot{m}_{10} \tag{27}$$

The energy balance for the absorption chiller evaporator is written as follows:

$$\dot{m}_9 h_9 + \dot{Q}_{eva} = \dot{m}_{10} h_{10} \tag{28}$$

The exergy balance for the absorption chiller evaporator is calculated as follows:

$$\dot{Ex}_{d,eva} = \dot{m}_{10}\left(\dot{Ex}_9 - \dot{Ex}_{10}\right) + (1 - T_0/T_{con})\dot{Q}_{con} \tag{29}$$

3.9 Absorption chiller absorber

The concentration and mass balance equation for absorber is written as follows:

$$\dot{m}_1 x_1 = \dot{m}_6 x_6 + \dot{m}_{10} x_{10} \tag{30}$$

$$\dot{m}_1 = \dot{m}_6 + \dot{m}_{10} \tag{31}$$

The energy and exergy balance equations for absorber are calculated as follows:

$$\dot{m}_6 h_6 + \dot{m}_{10} h_{10} = \dot{m}_1 h_1 + \dot{Q}_{abs} \tag{32}$$

$$\dot{m}_6 \dot{Ex}_6 + \dot{m}_{10} \dot{Ex}_{10} = \dot{m}_1 \dot{Ex}_1 + (1 - T_0/T_{abs})\dot{Q}_{abs} + \dot{Ex}_{\mathrm{d,abs}} \tag{33}$$

3.10 Absorption chiller pump

The mass balance and consumption power of the absorption chiller pump are calculated as follows:

$$\dot{m}_1 = \dot{m}_2 \tag{34}$$

$$\dot{W}_p = \dot{m}_1(h_2 - h_1) \tag{35}$$

The energetic coefficient of performance is calculated as follows:

$$COP_{en} = \dot{Q}_{eva}/\dot{Q}_{gen} \tag{36}$$

3.11 Kalina cycle turbine

The power of Kalina cycle is written as follows:

$$\dot{W}_{t,kc} = \dot{m}_{kc}(h_{18} - h_{19}) \tag{37}$$

The turbine isentropic efficiency can be written as follows:

$$\eta_t = (h_{18} - h_{19})/h_{18} - h_{19,s} \tag{38}$$

3.12 Kalina cycle pump

The Consumption Power of the Kalina cycle pump is calculated as follows:

$$\dot{W}_{p,kc} = \dot{m}_{kc}(h_{20} - h_{19}) \tag{39}$$

3.13 Kalina cycle condenser

The heat transfer rate in the condenser is calculated as follows:

$$\dot{Ex}_{d,con,kc} = (1 - T_0/T_{con})\dot{Q}_{con,kc} \tag{40}$$

The energy and exergy efficiency of the Kalina cycle are calculated as follows:

$$\eta_{en,kc} = \dot{W}_{net,kc}/\dot{Q}_{boiler} \tag{41}$$

$$\eta_{ex,kc} = \dot{W}_{net,kc}/\dot{Ex}_{boiler} \tag{42}$$

The net power of the Kalina cycle is calculated as follows:

$$\dot{W}_{netkc} = \dot{W}_{t,kc} - \dot{W}_{p,kc} \tag{43}$$

3. System energy and exergy efficiency

Energy and exergy efficiency of the trigeneration system are calculated as follows:

$$\eta_{en,system} = (\dot{W}_{tur} + \dot{Q}_{dwh} + \dot{Q}_{eva} - \dot{W}_{p,solar} - \dot{W}_{p,kc})/\dot{Q}_{solarcycle}$$

$$\eta_{ex,sys} = (\dot{W}_{tur} + \dot{Q}_{eva}(1 - T_0/T_{eva}) - \dot{W}_{p,kc} + \dot{Q}_{dwh}(1 - T_0/T_{dwh}) - \dot{W}_{p,sc})/\ \dot{Q}_{solar}(1 - T_0/T_{sun}) \tag{44}$$

4. Economic analysis

Economic analysis is a powerful tool for evaluating systems. The parameters used in the evaluation of economic analysis include the product cost, the fuel cost, the cost of the process or energy conversion, the cost of equipment, the cost of maintenance and etcetera. Expenses of investment, operating, and maintenance (Z) can be defined as [25]:

$$\dot{Z}_k = Z_k CRF\ \varphi/(N \times 3600) \tag{45}$$

In Eq.(45), Z_k is the cost of purchasing k components, (φ) maintenance and repairing factor and (N) represent the number of the hours of plant operation per year. Annual capital recovery factor (*CRF*) is defined as follows [25]:

$$CRF = i \times (i+1)^n/((i+1)^{n-1}) \tag{46}$$

where i is interest rate.

5. Results and discussion

Using the equations and input data of the trigeneration the system was modeled based on MATLAB software. The assessment is carried out in dynamic and static forms.

5.1. Dynamic analysis

In dynamic form, total cost rate, energy and exergy efficiency are varied by changing solar radiation. Fig.4 displays variation of total cost rate in this period. Scattered distributions show that the many scattered cost is equal to 8.294 dollars per hour in Fig.4.

Scattered distribution of the system energy efficiency has been shown in Fig.5. Scattered distributions show that the many scattered energy efficiency is equal to 19.7% in Fig.5.

Scattered distributions show that the many scattered exergy efficiency is equal to 19.81% in Fig.6.

Figures 4,5 show that maximum total cost rate, energy and exergy efficiency are equal to 15.1 dollars per hour by 33% and 36.47%, respectively.

5.2. Static analysis

In static form, the solar radiation is assumed constant. Therefore, the system variables are computed for the unique values. The results of

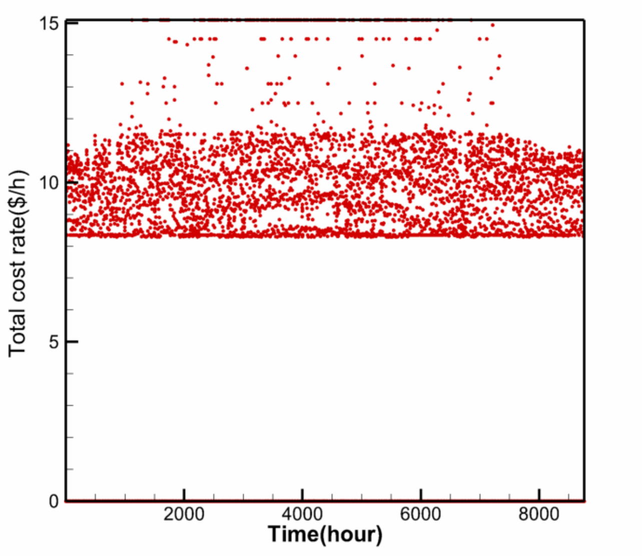

Fig. 4. Scattered distribution of total cost rate]

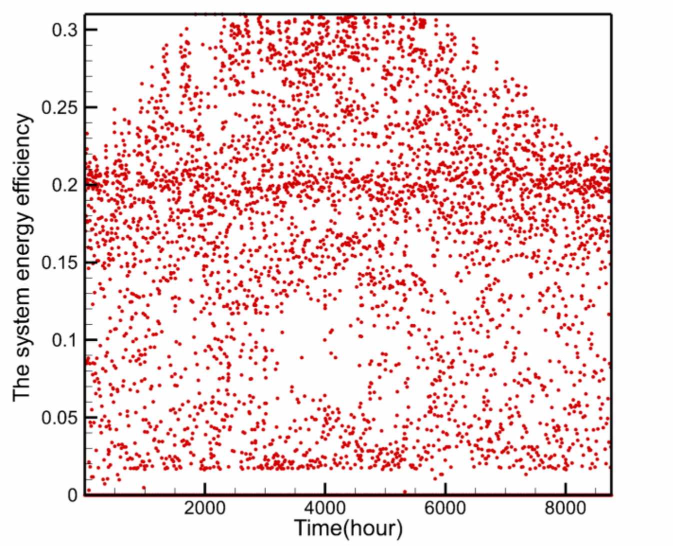

Fig. 5. Scattered distribution of the system energy efficiency

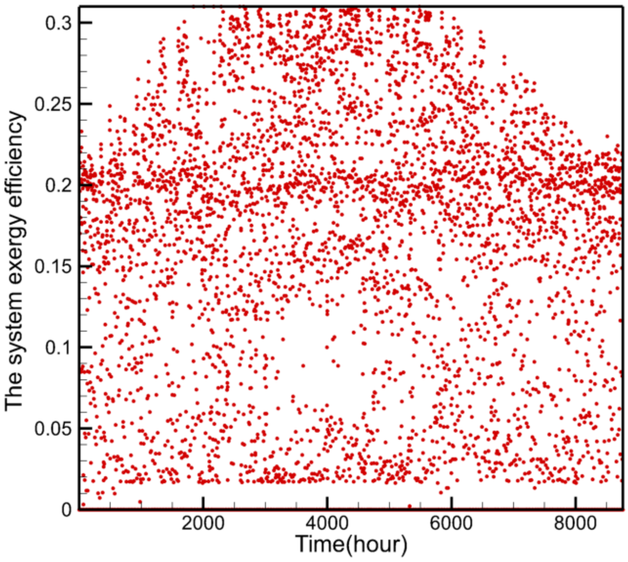

Fig. 6. Scattered distribution of the system exergy efficiency

energy analysis have been shown in Table 2. Table 2, the energy efficiency of the system, absorption chiller coefficient of performance, turbine output power and cooling load are respectively equal to 0.8145, 546.7 and 28.52 kW by 17.37%,.

The second law of thermodynamics is the verification of thermodynamic systems. In the perspective of exergy or useful energy, the system is evaluated by the destruction exergy. The results of destruction exergy analysis have been shown in Table 3 below.

The solar cycle has the highest destructed exergy due to the high temperature gradient in this cycle. The total system exergy efficiency is approximately by 18.82% and defined as the macroscopic ratio of input and output energies.

Currently, economic analysis of renewable energy has become important. Purchase cost rate has been shown in Table 4. According to Table 4, the highest purchase cost rate is for the solar collector approximately by 57% of the total cost.

The purchase cost rate of the collector is a function of collector size.

The term thermal conductivity is due to the finite heat transfer in heat exchanger. The results of calculating the thermal conductivity have been presented in Table 5.

Table 2. Energy analysis results

Variable	Value
The heat transfer rate from the collector to heat transfer fluid Therminol-66 (MW)	3.53
Heat transfer rate to Kalina cycle (MW)	2.75
Heat transfer rate to generator (kW)	35
Turbine production power (kW)	546.7
Evaporator Cooling load (kW)	28.52
Heat transfer rate domestic water heater (kW)	321.57
Absorption chiller coefficient of performance	0.8145
System energy efficiency (%)	17.37

Table 3. Exergy analysis results in subsystems

Variable	Base case design value
Exergy destruction in the solar cycle (MW)	2.402
Exergy destruction in the Kalina cycle (kW)	264.61
Exergy destruction in the absorption chiller (kW)	8.67
System exergy efficiency (%)	18.82

Table 4. Purchase cost rate

Variable	**Purchase cost base case**
Parabolic solar collector ($/h)	5.453
Domestic water heater ($/h)	0.00002
Kalina Cycle Condenser ($/h)	0.1128
Absorption chiller ($/h)	0.3332
Kalina Cycle Pump ($/h)	0.3032
Boiler ($/h)	2.117
Turbine ($/h)	1.315
Total cost rate($/h)	9.63

Table 5. Thermal conductivity calculation results

Component	**Thermal conductivity**
Boiler (kW/K)	41.11
Domestic water heaters (kW/K)	9.28
Kalina Condenser (kW/K)	56.94
Absorption chiller generator (kW/K)	0.1
Absorption chiller condenser (kW/K)	1.25
Absorption chiller absorber (kW/K)	0.11
Absorption chiller evaporator (kW/K)	1.17
Total thermal conductivity (kW/K)	109.96

5.2.1 Optimization

Optimization is defined as to find maximum or minimum dependent variables with variation in decision variables. In this paper, optimization was performed by the genetic algorithm. The genetic algorithm was invented by Holland with evaluating the imitation of biological evolution [26]. Today, the genetic algorithm has become an evolutionary computing tool. Genetic algorithm is one of the evolutionary methods that performs optimization by random search. The genetic algorithm has two principles: selection and generation; these two principles have been derived from nature [27]. In this paper, objective functions are energy efficiency, exergy efficiency and total cost rate. Decision variables include mass flow rate of solar cycle and mass flow rate of Kalina cycle thermal conductivity of boiler, thermal conductivity of domestic water heaters, thermal conductivity of adsorption chiller generator, thermal conductivity of adsorption chiller condenser, thermal conductivity of absorption chiller absorber, thermal conductivity of absorption chiller evaporator, thermal conductivity of Kalina cycle condenser and pressure ratio of Kalina cycle. The results of trigeneration system optimization have been shown based on maximum power criterion in Table 6. Therefore, if the system is designed according to the conditions of Table 6, the system can reach the maximum power. In order to correctly compare the criteria, the relative variations are used in which the reference case is the same as the base case.

As shown in Table 6. Produced power, energy efficiency, exergy efficiency and total cost rate are increased by 28%, 12.32%, of 13.97% and 7.68%, respectively and also, this result is obtained in comparison with the base case. Therefore optimization based on the maximum power criterion, in addition to increasing the total cost rate and power. Optimization based on the maximum energy efficiency criterion has been tabulated in Table 7. Thus, by designing the system according to Table 7 or, in other words, the maximum energy efficiency criterion, the output power, the energy efficiency and total cost rate are increased by 3.74%, 6.64% and 6.023%, respectively; however, the exergy efficiency is decreased by 6.64% approximately relative to the base case. Optimization based on the energy efficiency criterion is a classic optimization in thermodynamics. Therefore, optimization based on the maximum energy efficiency criterion leads to an increase in the total cost and power.

Exergy efficiency is widely used as the objective function in thermodynamic analysis. Exergy efficiency is defined as the comparison of several macroscopic forms of energy with different qualities. The trigeneration system optimization results based on the maximum exergy efficiency criterion have been shown in Table 8. Then, optimization based on the exergy efficiency criterion leads to an increase in exergy efficiency and total cost rate by 16.31% and 5.09%, respectively and a decrease in the power output, energy efficiency by 34.88% and 8.98%, respectively.

Table 6. Optimization based on the criterion of maximum power

Variable	Value
Pressure ratio of Kalina cycle	141.37
Mass flow rate of solar cycle (kg/s)	6
Mass flow rate of Kalina cycle (kg/s)	2.0802
Thermal conductivity of boiler (kW/K)	80.95
Thermal conductivity of domestic water heater (kW/K)	10.128
Thermal conductivity of adsorption chiller generator (kW/K)	0.1025
Thermal conductivity of adsorption chiller condenser (kW/K)	1.25
Thermal conductivity of adsorption chiller absorber (kW/K)	0.109
Thermal conductivity of adsorption chiller evaporator (kW/K)	1.165
Thermal conductivity of Kalina cycle condenser (kW/K)	54.98
Power (kW)	700.2
Energy efficiency (%)	19.51
Exergy efficiency (%)	21.45
The total cost rate ($/h)	10.37

Table 7. Optimization based on the criterion of energy efficiency

Variable	Value
Pressure ratio of Kalina cycle (kW/K)	127.99
Mass flow rate of solar cycle	6
Mass flow rate of Kalina Cycle	2
Thermal conductivity of boiler (kW/K)	58.86
Thermal conductivity of domestic water heater (kW/K)	10.13
Thermal conductivity of adsorption chiller generator (kW/K)	0.1025
Thermal conductivity of adsorption chiller condenser (kW/K)	1.2469
Thermal conductivity of adsorption chiller absorber (kW/K)	0.109
Thermal conductivity of adsorption chiller evaporator (kW/K)	1.1652
Thermal conductivity of Kalina cycle condenser (kW/K)	58.92
Power (kW)	567.14
Energy efficiency (%)	19.7
Exergy efficiency (%)	17.57
Total cost rate ($/h)	10.21

Table 8. Optimization based on the criterion of exergy efficiency

Variable	Value
Pressure ratio of Kalina cycle (kW/K)	143.123
Mass flow rate of solar cycle (kg/s)	6
Mass flow rate of Kalina Cycle (kg/s)	2
Thermal conductivity of boiler (kW/K)	57.082
Thermal conductivity of domestic water heater (kW/K)	10.127
Thermal conductivity of adsorption chiller generator (kW/K)	0.103
Thermal conductivity of adsorption chiller condenser (kW/K)	1.25
Thermal conductivity of adsorption chiller absorber (kW/K)	0.109
Thermal conductivity of adsorption chiller evaporator (kW/K)	1.1652
Thermal conductivity of Kalina cycle condenser (kW/K)	58.93
Power (kW)	567.5
Energy efficiency (%)	15.81
Exergy efficiency (%)	21.89
Total cost rate($/h)	10.12

The results show that power criteria are superior to energy and exergy efficiency criteria. As a result, this research proved that the results of the thermodynamic analysis are closer to the ideal state in power criterion of the efficiency criterion.

7. Conclusion

One of the ways to achieve sustainable development for developing countries such as Iran is to pay more attention to potential of renewable energy sources in each climate. Among renewable energies, solar energy is a good alternative for fossil fuels. The climatic and weather conditions in the city of Zahedan, provide good conditions for the operation of solar systems. In this study, energy, exergy, and cost analysis and assessment were performed in dynamic and static forms. In this paper, optimization criteria including maximum power, energy and exergy efficiency were compared to each other. So, the criteria based on the power were better than criteria based on efficiency i.e. energy and exergy efficiency. Therefore, the power-based analysis comparing efficiency-based analysis was closer to the ideal state. Finally, the power analysis was presented as a powerful thermodynamic tool..

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