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Research Article

Thermoeconomic analysis of a geothermal and solar assisted combined organic Rankine and absorption cycle

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ABSTRACT

In this paper, a geothermal and solar-assisted combined system is designed for the electricity and cooling of residences. The geothermal water from the geothermal resource and the heat transfer fluid heated in the parabolic trough collector is used as the heat source in the absorption cooling system. The organic Rankine cycle (ORC) generates power with geothermal water and heat transfer fluid from the absorption cooling cycle. The produced power is supported to the grid. Engineering Equation Solver (EES) and Aspen Plus program are used for thermodynamic and thermoeconomic analysis of the combined system. In these analyzes, the geothermal and solar energy values of Afyonkarahisar city are considered. Geothermal water at a temperature of 130 ºC and a mass flow rate of 85 kg/s and a solar source at 600 W/m^2 radiation is used for the combined system. Parametric studies are performed to demonstrate the way unit electricity and cooling costs change according to the geothermal water temperature and solar radiation. The cooling capacity and the net power output of the system are 2720 kW and 2235 kW, respectively. The unit costs of cooling and electricity in the combined system are calculated 0.017 $/kWh and 0.074 $/kWh, respectively.

1. Introduction

Climate change is a global problem facing the whole world today. The leading cause of this problem is global warming resulting from greenhouse gas emissions. Carbon dioxide (CO_2) is the primary greenhouse gas released from burning fossil fuels such as oil, natural gas, and coal [1]. Meeting the energy demand of any country is of great importance for the development and progress of that country. Especially in the last 20 years, the countries' energy demands have increased due to the increase in the world population. In order to meet this increase in demand, alternative and uninterrupted energy sources are needed [2].

Due to the depletion of fossil fuels and their harmful environmental effects, the search for sustainable and environmentally friendly alternative energy sources has accelerated in recent years. Investments in renewable energy sources are increasing day by day. As a result of the development of engineering applications and technology, the efficiency obtained from renewable energy sources is constantly increasing [3].

Geothermal energy is a renewable source of heat accumulated underground. Geothermal energy reaches the earth's surface in different forms and proportions. Geothermal energy is a renewable energy source without greenhouse gas emissions and environmental pollution [4]. Since geothermal energy works almost all year round, it can produce energy continuously. It is a very efficient source for power generation, district heat, and cooling [5].

In recent years, interest in solar energy has increased worldwide. Solar energy is a renewable and sustainable energy source. The thermal energy of solar energy is an essential alternative to fossil fuels [6]. Cooling systems are expensive systems due to high electricity consumption. Solar and geothermal energy are alternative energy sources to eliminate this electricity cost [7].The most mature cooling technologies are sorption machines, absorption, and adsorption cooling systems. [8] Absorption cooling systems with LiBr-H_2O operate at lower thermal energies than absorption cooling systems with NH_3-H_2O. Absorption cooling systems with LiBr-H_2O have higher efficiency because they work at the higher coefficient of performance (COP) values [9]. The absorption coolingsystem with LiBr-H_2O is the most suitable cooling system due to its low-temperature operation and simple structure [10]. The

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single-effect absorption cooling system with LiBr-H_2O has a wide range of applications [11].

Combined cooling and power (CCP) systems are highly efficient systems that can produce both cooling and electricity from one or more heat sources. It works with higher efficiency than independent cooling and power systems [12]. Fossil fuels operate the majority of cooling and power systems around the world. The fact that fossil fuels cause high carbon emissions and severe environmental problems has accelerated the transition to renewable energy sources [13].

Turkey has rich sources of renewable energy. Geothermal and solar-powered electricity production has become popular and common in Turkey, especially in recent years. The industrial output growth has increased Turkey's energy demand in recent years. In order to meet this energy demand, reduce external dependency and decarbonize the energy sector, the capacity of renewable energy sources should be maximized. [14].

Few studies on geothermal and solar-assisted electricity and cooling production are in the literature. These studies are presented in the literature review. Alibaba et al. [15] investigated a individual geothermal cycle and a hybrid geothermal-solar cycle to produce the cooling- heating power of the building. The exergoeconomic analysis of the cycles showed that the solar power plant has the highest cost. Calise et al. [16] proposed a hybrid geothermal-solar plant producing electricity, heat, and cool. As a result of the thermoeconomic analysis of the hybrid geothermal-solar power plant, the payback period of the plant is calculated as 16.7 years. Alirahmi et al. [17] developed a multi-generation geothermal and solar-powered energy system. As a result of thermoeconomics analysis and optimization, the exergetic efficiency and total unit cost of the system are 29.95% and 129.7 $/GJ. Ghasemi et al. [18] compared a hybrid system utilizing geothermal energy and parabolic collectors and the individual geothermal system. The solar and geothermal energy-powered hybrid system showed higher exergy efficiency than the individual geothermal system. Heberle et al. [19] have integrated solar energy into a geothermal-assisted ORC power plant. The geothermal and solar energy-assisted combined system and the individual geothermal system are compared. The combined system has 7.8% more electricity and power than the individual system. Mctigue et al. [20] designed a geothermal and solar energy assisted hybrid power plant. They considered a double flash for a geothermal resource and a concentrated collector for a solar resource and performed the energy and economic analysis of the hybrid power plant. The hybrid plant's unit electricity cost that increased power generation from 22 to 24 MW was obtained 0.07 ± 0.01 $/kWh. Kehvarparast et al. [21] studied thermodynamic analysis for a geothermal power plant hybridized with parabolic trough collectors. A thermodynamic analysis of the hybrid plant is performed. The energy consumption of the fan and the condenser decreased 47.32% and 33.58%, respectively. Haghghi et al. [22] have integrated solar-assisted an ORC and an absorption cooling cycle for power, heating and cooling production. The power, heating and cooling costs are calculated as 15.47 $/GJ, 10.27 $/GJ, and 11.44 $/GJ, respectively. Ayub et al. [23] designed a geothermal resource and parabolic solar collector system. The result of the thermoeconomic analysis indicated that the unit electricity cost of a hybrid system decreased by 2% compared to a standalone geothermal system.

This study performs thermodynamic and thermoeconomic evaluation of a combined absorption cooling and organic Rankine cycle [24]. The absorption cooling cycle for cooling residences and ORC for electricity of residences is considered. The purchased equipment cost of the combined system is calculated in the Aspen Plus program [25]. This paper is a novelty in adding a solar power system to an existing geothermal power plant in Afyonkarahisar. Through the developed model, electricity and cooling production are combined. Two useful outputs are obtained from the combined system. This study contributes to supplying the energy demand of Afyonkarahisar from renewable resources and competitive costs.

The steps to be applied in the study can be written as: (i) the combined system is modeled and solved thermodynamically in a computer environment, (ii) in the thermodynamic and thermoeconomic analysis of the combined system, the geothermal and solar energy values of Afyonkarahisar are used, (iii) parametric analyses of the combined system are performed at different geothermal water temperatures and solar radiation, (iv) unit electricity and cooling costs of the combined system are investigated under different conditions.

2. Description and Operating Principle

In this study, an integrated approach is developed to requirements residential buildings' cooling and electricity supply. In the absorption cooling cycle, the electrical input is replaced by renewable energy heat energy. The cooling process is provided by this heat energy and two working fluids. Conventional vapor compression cycles use a compressor to circulate the refrigerant and create pressure differences. The absorption cooling system circulates the coolant with the help of a secondary fluid or absorber.

Using parabolic trough solar collectors is one of the effective ways to benefit from solar energy with high efficiency. Parabolic trough collectors are used to produce steam from solar energy. The receiver tube of the parabolic trough collector is located along the focal line. In order to reduce heat losses, the surface of the receiver is covered with a glass cover tube along the focal line. The rays from the sun are reflected in the receiver tube by the parabolic reflective mirrors. Concentrated radiation reaching the receiver tube heats the heat transfer fluid circulating in the receiver, and solar radiation is converted into useful heat. This useful heat is used for power generation in ORC [26].

In Figure 1, hot geothermal water from the geothermal resource (at state 7) and hot heat transfer fluid (Therminol VP-1) heated in the parabolic trough collector (at state 10) is the heat input of the absorption cooling system. The refrigerant vapor in the evaporator and is sent to the absorber (at state 21). The refrigerant vapor is absorbed by lithium bromide in the absorber. The weak solution of lithium bromide enters (at state 13) the heat exchanger by increasing the pressure by the pump. The weak solution of lithium bromide is heated in the heat exchanger and enters the generator (at state 14). With the heat energy transfer of hot geothermal water and hot heat transfer fluid, the refrigerant vapors and leaves (at state 18) the solution. The refrigerant vapor leaving the generator enters the condenser and condensed it in the condenser. The pressure of the liquid refrigerant is reduced in the expansion valve and sent to the evaporator (at state 20). As the refrigerant passes through the evaporator, it absorbs the heat of the hot water, and cold water is produced (at state 23). The cold water leaving the evaporator is sent to the heat exchanger for district cooling, producing cold air (at state 26). The cold air produced is sent to the buildings for district cooling.

The ORC uses the geothermal water and heat transfer fluid as the heat source for electricity generation. R134a is used as the working fluid in the ORC. The geothermal water (at state 8) and heat transfer fluid (at state 11) leaving the generator of the absorption cooling cycle enters the heat exchanger of the ORC to heat a working fluid. The working fluid leaves (at state 3) the heat exchanger as vapor. The vaporized working fluid is sent to the turbine to generate electricity. Electricity is supplied to the grid. The vaporized working fluid leaving the turbine is sent (at state 4) to the water-cooled condenser and condensed in the condenser. The working fluid leaves (at state 1) the condenser as liquid, and the cycle is completed. The geothermal water is reinjected (at state 9) back to the resource. The Therminol VP-1 fluid is pumped (at state 28) to the parabolic trough collector to be reheated.

The geothermal water enters the combined system at 130 °C and is reinjected back to the resource at 60°C. The solar radiation for the solar source is 600 W/m^2, and the mass flow rate of working fluid circulating in the parabolic collector is 0.2 kg/s [27].

3. Thermodynamic Analysis

Thermodynamic assumptions for the geothermal and solar-assisted combined organic Rankine and absorption cycle are given following. The equipment of the system operates on a steady-state and steady flow condition. The potential and kinetic changes are negligible. The isentropic efficiency of pumps and turbines is 85%.The pressure drops and losses in the equipment of the system are negligible. Environment temperature is 25°C and atmospheric pressure is 100 kPa. Considering the temperature range and solar radiation, Therminol VP-1 is chosen as the working fluid in the parabolic collectors [28].

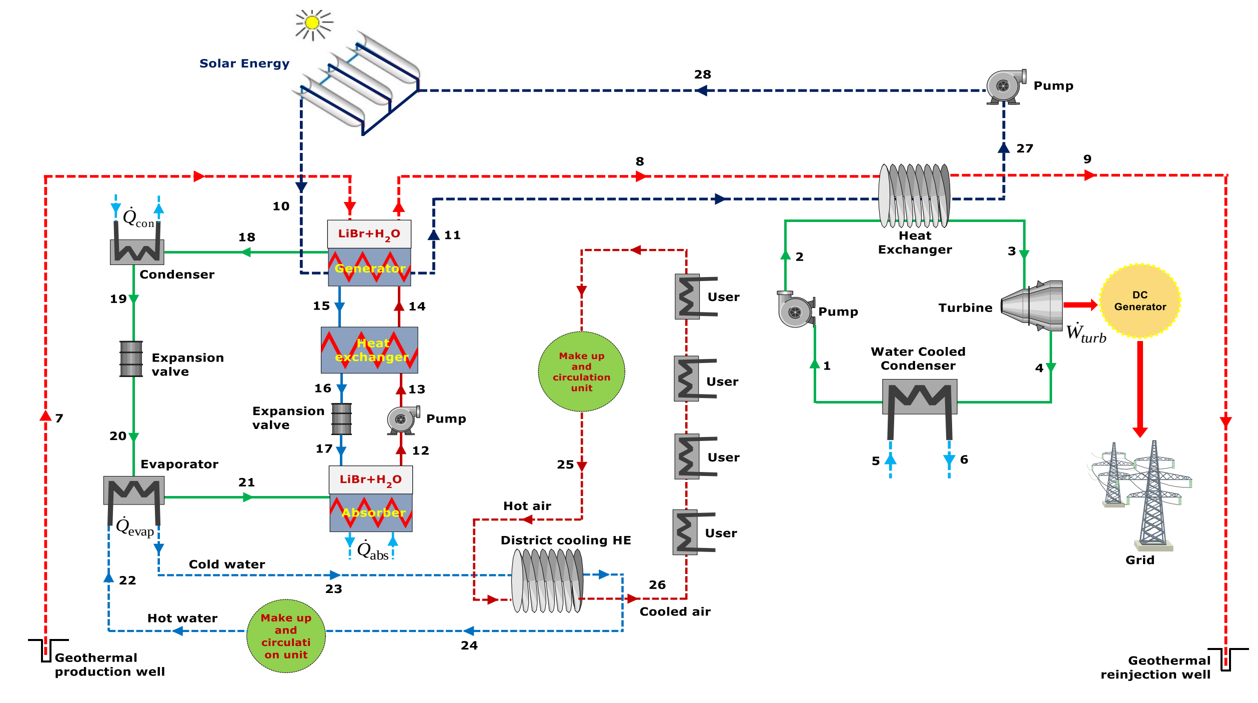

Figure 1. Geothermal and solar energy combined system

The COP value of the absorption cooling cycle is calculated from:

$$COP_{ARC} = \frac{\dot{Q}_{eva}}{(\dot{Q}_{gen} + \dot{W}_{pump})} \quad (1)$$

where, $\dot{Q}_{eva}$ is the cooling capacity of the evaporator, $\dot{Q}_{gen}$ is the heat capacity of the generator and $\dot{W}_{pump}$ is pump power.

The exergy efficiency of the absorption cooling cycle can be determined with the help of the following equation:

$$\varepsilon_{ARC} = \frac{-\dot{Q}_{eva}\left(T_0 / T_E - 1\right)}{\dot{Q}_{gen}\left(T_0 / T_G - 1\right)} \quad (2)$$

where, T_0 is ambient temperature, T_E is evaporator temperature and T_G is generator temperature.

The power output from the ORC is calculated from [29]:

$$\dot{W}_{net} = \dot{W}_T - \dot{W}_P \quad (3)$$

where, $\dot{W}_T$ is turbine power and $\dot{W}_P$ is pump power.

The overall energy efficiency of ORC is the ratio of net power output to energy input, and the overall exergy efficiency of ORC can be defined as [29]:

$$\eta_{ORC} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} \quad (4)$$

$$\varepsilon_{ORC} = \frac{\dot{W}_{net}}{\dot{E}x_{in}} \quad (5)$$

Energy efficiency for the overall system can be calculated by ratio of net power output from ORC and the cooling capacity of the evaporator to the total heat energy entering the overall system:

$$\eta_{overall} = \frac{\dot{W}_{net} + \dot{Q}_{eva}}{\dot{Q}_{geo} + \dot{Q}_{solar}} \quad (6)$$

For the combined system, the expression of exergy efficiency determined as follows:

$$\varepsilon_{overall} = \frac{\dot{W}_{net} + \dot{Q}_{eva}((T_0 / T_E) - 1)}{\dot{E}x_{geo} + \dot{E}x_{solar}} \quad (7)$$

4. Thermoeconomic Analysis

Engineering economics is a science that offers techniques for the economic analysis of engineering systems [30]. Determining the cost of the system and choosing the best alternative is a fundamental issue in engineering economics. In economic analysis, the operating and maintenance costs and the levelized capital investment costs of the investigated system are provided [29].

The capital recovery factor (CRF) can be calculated depending on the interest rate (i) and the life time period of the system (n) [31]:

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (8)$$

The $\dot{Z}$ is the total cost rate ($/h) summation with ($\dot{Z}^{CI}$) capital I nvestment and ($\dot{Z}^{OM}$) the operating and maintenance costs [31]:

$$\dot{Z} = \dot{Z}^{\text{CI}} + \dot{Z}^{\text{OM}} \quad (9)$$

Thermoeconomics is a discipline that considers both thermodynamics and economics. Many different economic applications can be used in engineering systems. Considering exergy values would be a better option for engineering economics. Therefore, the specific exergy costing method (SPECO) is preferred for thermoeconomic analysis. The fundamental principles of the SPECO method are the direct application of exergy flows instead of matter and energy flows. The three steps of this method are; (i) identification of exergy streams, (ii) definition of fuel and product (iii) cost equations and derivation of auxiliary equations [32].

In the SPECO method, all exergy streams are associated with a cost. Thus, the exergy transfer rate associated with entering and exiting streams of the equipment, the exergy transfer rate associated with output work and input heat can be expressed [32]:

$$\dot{C}_{\text{i}} = c_{\text{i}}\dot{E}x_{\text{i}} = c_{\text{i}}(\dot{m}_{\text{i}}ex_{\text{i}}) \quad (10)$$

$$\dot{C}_{\text{e}} = c_{\text{e}}\dot{E}x_{\text{e}} = c_{\text{e}}(\dot{m}_{\text{e}}ex_{\text{e}}) \quad (11)$$

$$\dot{C}_{\text{w}} = c_{\text{w}}\dot{W} \quad (12)$$

$$\dot{C}_{\text{q}} = c_{\text{q}}\dot{E}x_{\text{q}} \quad (13)$$

For a k component receiving the heat and the power can be written as [32]:

$$\sum_{\text{e}}\left(c_{\text{e}}\dot{E}x_{\text{e}}\right)_{\text{k}} + c_{\text{w,k}}\dot{W}_{\text{k}} = c_{\text{q,k}}\dot{E}x_{\text{q,k}} + \sum_{\text{i}}\left(c_{\text{i}}\dot{E}x_{\text{i}}\right)_{\text{k}} + \dot{Z}_{\text{k}} \quad (14)$$

where, c_e, c_i, c_w and c_q denote average costs per unit of exergy in dollars per gigajoule ($/GJ). c_i and c_e are the cost per unit associated with the inlet and outlet exergy stream. c_w and c_q are the cost per unit associated with the output work and heat [32].

The certain assumptions are performed in the economic and thermoeconomics analysis. The annual working hour of the system is 7446 hours and its economic life is 20 years. The annual interest rate (i, interest rate) is assumed as 10% [31].

Primarily, combined system simulated and operated in the Aspen Plus program and the purchase costs of the equipment are obtained. Then, in the EES program, the necessary data calculated for the system are coded into the program by us, and the results of thermoeconomic analysis are obtained.

5. Results and Discussion

Energy, exergy and economic analysis results of the combined system are presented in this section. The thermophysical properties of the geothermal water, R134a fluid and lithium-bromide ($LiBr-H_2O$) solution are provided from the EES program. For the thermoeconomic analysis to be concluded correctly, the thermodynamic analysis should be performed carefully. Therefore, thermodynamic analysis is critical to the economic results of the study.

The geothermal fluid and heat transfer fluid (Therminol VP-1), 25,261 kW of heat and 5578 kW of exergy are input to the combined energy system. Geothermal water (130°C and 85 kg/s) from the production well and Therminol VP-1 fluid (145°C and 0.2 kg/s) from the parabolic trough collector are heat sources of the absorption cooling system. Considering these thermodynamic properties, the heat transferred to the generator is calculated as 3634 kW. The cooling capacity of the absorption cooling system is 2720 kW. The actual COP value of the absorption cooling system is determined as 0.748 from Equation (1). The second law efficiency of the absorption cooling system is 22.5% from Equation (2).

Table 1. Thermoeconomics values of components [22]

Component	**PEC ($)**	$\dot{Z}$ **($/h)**
ORC-Pump	70,000	1.17
ORC-Heat exchanger	325,000	5.43
ORC-Turbine	480,000	8.028
ORC-Condenser	325,000	5.436
Pump-1	5000	0.083
Expansion valve-1	5000	0.083
Heat exchanger-1	22,000	0.367
Generator	100,000	1.672
Condenser	26,900	0.449
Expansion valve-2	5000	0.083
Evaporator	11,500	0.192
Absorber	94,200	1.575
Heat exchanger-2	11,500	0.192
Pump-2	1000	0.016
Parabolic collector	72,000	1.203
Total PEC	**1,554,100**	-

The geothermal water and Therminol VP-1 fluid from the absorption cooling system, 21,579 kW of heat and 4505 kW of exergy are the input of the ORC in which the electricity is produced. The net power obtained from the ORC is determined as 2235 kW. The first law efficiency of ORC is calculated as 10.3% and second law efficiency as 49.6%. The first law efficiency of the combined system is 19.6%, and the second law efficiency is 43.7%.

The annual working hour for the system is 7446 hours and its economic life is 20 years. The annual interest rate (i) we use in economic analysis has been accepted as 10%. The CRF value is calculated as 0.1175. Table 1 below created for the system shows the purchased equipment costs (PEC) of the model equipment and the total cost rate ($\dot{Z}$). The total PEC of the equipment used in the model is calculated as $ 1,554,100.

Based on the SPECO method, all equations used in the thermoeconomic analysis of the combined system are given in Table 2.

Table 2. Thermoeconomic equations of the components associated with exergy

Component	**Exergetic cost rate balance equation**	**Auxiliary equations**
ORC-Pump	$\dot{C}_1+\dot{Z}_P+\dot{C}_{W_P}=\dot{C}_2$	c_1 (is known) c_2 (variable)
ORC-Heat exchanger	$\dot{C}_2+\dot{C}_8+\dot{C}_{11}+\dot{Z}_{HE}=\dot{C}_3+\dot{C}_9+\dot{C}_{27}$	$c_8=c_9$
ORC-Turbine	$\dot{C}_3+\dot{Z}_T=\dot{C}_{W_T}+\dot{C}_4$	$c_3=c_4$ $c_{electricity}$ (variable)
ORC-Condenser	$\dot{C}_4+\dot{C}_5+\dot{Z}_{WCC}=\dot{C}_1+\dot{C}_6$	$c_5=0$
Pump-1	$\dot{C}_{12}+\dot{Z}_P+\dot{C}_{W_P}=\dot{C}_{13}$	c_{12} (is known)
Heat exchanger-1	$\dot{C}_{13}+\dot{C}_{15}+\dot{Z}_{HE}=\dot{C}_{14}+\dot{C}_{16}$	$c_{15}=c_{16}$
Generator	$\dot{C}_7+\dot{C}_{10}+\dot{C}_{14}+\dot{Z}_{GEN}=\dot{C}_8+\dot{C}_{11}+\dot{C}_{15}+\dot{C}_{18}$	$c_7=c_8$
Condenser	$\dot{C}_a+\dot{C}_{18}+\dot{Z}_{CON}=\dot{C}_b+\dot{C}_{19}$	$c_a=0$
Evaporator	$\dot{C}_{20}+\dot{C}_{22}+\dot{Z}_{EVA}=\dot{C}_{21}+\dot{C}_{23}$	$c_{22}=0$ $c_{20}=c_{21}$
Absorber	$\dot{C}_c+\dot{C}_{17}+\dot{C}_{21}+\dot{Z}_{ABS}=\dot{C}_d+\dot{C}_{12}$	$c_c=0$
Heat exchanger-2	$\dot{C}_{23}+\dot{C}_{25}+\dot{Z}_{DHE}=\dot{C}_{24}+\dot{C}_{26}$	$c_{25}=0$ $c_{23}=c_{24}$
Parabolic collector	$\dot{C}_{28}+\dot{Z}_{PTC}=\dot{C}_{10}$	c_{28} (is known)

In consideration of technical assumptions, auxiliary equations are solved in the EES program accordingly.

The unit cooling cost is 0.074 $/kWh (20.77 $/GJ) in the absorption cooling cycle. The unit electricity cost (LCOE) produced in the ORC cycle is 0.017 $/kWh (4.71 $/GJ).

In this section, the variation of unit cooling and electricity costs in different geothermal water temperatures and solar radiation are investigated. In Figures 2 and 3, the geothermal water temperature varies between 120 and 150°C, while the solar radiation is constant at 600 W/m^2. When Figure 2 is observed, the increase in geothermal water temperature caused an increase in unit cooling cost. This is because the absorption cooling cycle can use a lower proportion of geothermal energy at a higher geothermal source temperature.

Figure 3 indicates the variation of unit electricity cost at different geothermal temperatures. At high temperatures, the unit electricity cost decreases linearly because more power is obtained from geothermal energy. The unit cooling and electricity costs corresponding to the geothermal data points are given in Table 3.

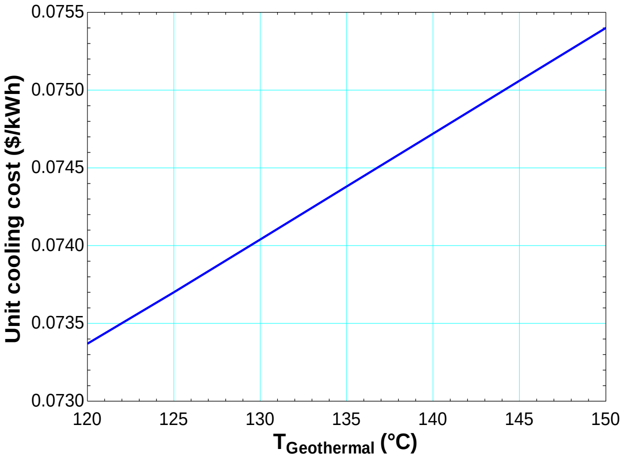

Figure 2. Variation of unit cooling cost with the geothermal temperature.

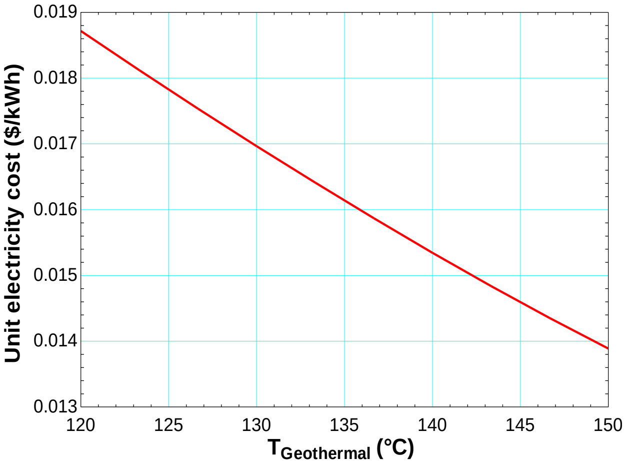

Figure 3. Variation of unit electricity cost with the geothermal temperature

Table 3. Unit cooling and electricity cost corresponding to geothermal data points.

Geothermal temperature (°C)	Unit cooling cost ($/kWh)	Unit electricity cost ($/kWh)
120	0.0733	0.0187
125	0.0737	0.0178
130	0.0740	0.0169
135	0.0743	0.0161
140	0.0747	0.0153
145	0.0751	0.0145
150	0.0754	0.0138

In Figures 4 and 5, the solar radiation varies between 300 and 1000 W/m^2, while the geothermal water temperature is constant at 130°C. Figure 4 shows the variation of unit cooling cost at different solar radiations. When Figure 4 is observed, the unit cooling cost increases because solar energy can be used at a lower level with the increase of solar radiation. Since the absorption cooling cycles can absorb and use the energy at high temperatures to a certain ratio, the COP and cooling capacity of the cooling cycles decrease with the increase in the source temperature. Thus the cooling costs increase linearly.

When Figure 5 is observed, solar radiation directly affects the unit electricity cost. With the increase of solar radiation, the production cost of electricity decreases because more energy is used. This parametric study showed that the effect of solar radiation on system outputs (unit cooling and electricity cost) is lower than that of geothermal water. This is because the power output is far less than geothermal resource due to the considerable amount of losses in the parabolic collectors. Table 4 for solar data points shows unit cooling and electricity costs.

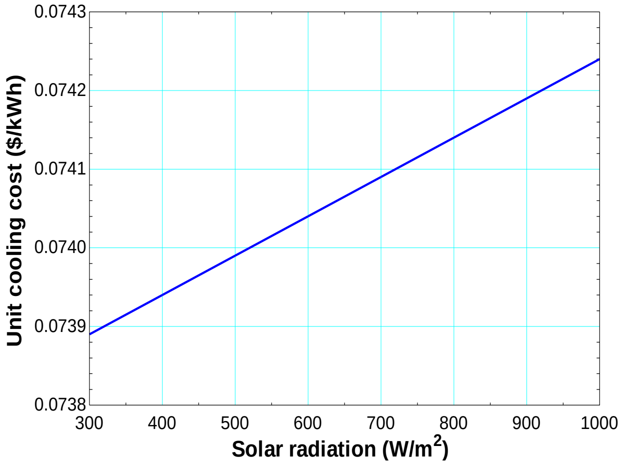

Figure 4. Variation of unit cooling cost with the solar radiatio

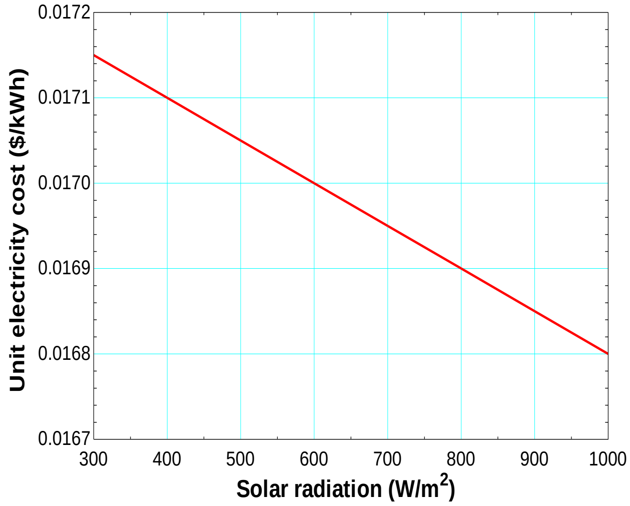

Figure 5. Variation of unit electricity cost with the solar radiation

Table 4. Unit cooling and electricity cost corresponding to solar data points

Solar radiation (W/m^2)	Unit cooling cost ($/kWh)	Unit electricity cost ($/kWh)
300	0.07389	0.01715
400	0.07394	0.01710
500	0.07399	0.01705
600	0.07404	0.0170
700	0.07409	0.01695
800	0.07414	0.01690
900	0.07419	0.01685
1000	0.07424	0.01680

5.1 Proposed System Validation and Comparison

This geothermal and solar energy combined system has a 2720 kW cooling capacity and 2235 kW net power. The combined system’s first and second law efficiencies are 19.6% and 43.7%. The unit cooling and electricity cost is 0.074 $/kWh (20.77 $/GJ) and 0.017 (4.71 $/GJ) $/kWh, respectively.

Alirahmi et al. [17] developed a multi-generation solar and geothermal energy-powered system. According to thermodynamic analysis and optimization, the exergetic efficiency of the system is 29.95%, and the total unit cost is 129.7 $/GJ. Heberle et al. [19] have integrated solar energy into a geothermal assisted ORC plant. The obtained results of the system show the LCOE with 0.145 $/kWh considering costs for operation and maintenance of 0.0023 $/kWh. Mctigue et al. [20] performed thermodynamic and thermoeconomic analysis of a hybrid plant integrating heat from a concentrating solar collector for a geothermal plant. The energy efficiency of the hybrid plant is 17.3%. The levelized cost of electricity (LCOE) of the hybrid plant is obtained 0.07 $/kWh. Haghghi et al. [22] have integrated solar-assisted an ORC and an absorption cooling cycle for power, heating and cooling production. The power, heating, and cooling costs are calculated as 15.47 $/GJ, 10.27 $/GJ, and 11.44 $/GJ. Behnam et al. [33] designed a geothermal energy-assisted system for producing freshwater, heating, and electricity. Electricity is generated in the ORC. The unit electricity cost is 0.0402 $/kWh. Ghiasirad et al. [34] performed a thermoeconomics analysis of geothermal-assisted combined power, heating and cooling system. The absorption chiller's COP and cooling capacity are 0.798 and 4991 kW. The unit electricity and cooling costs of the combined system are calculated 0.562 and 0.201 $/kWh, respectively.

6. Conclusions

Geothermal and solar energy is widely used in many countries today. Geothermal and solar energy is among the fastest-growing renewable energy technologies in Turkey in recent years. Geothermal and solar energy can be widely used in electricity generation, heating, cooling, industrial applications, and greenhouse cultivation. The use of economically renewable energy sources in heating and cooling also makes electricity production more profitable. In addition, the use of renewable energy sources in power and cooling production helps to eliminate fossil fuel emissions. The most significant advantage of renewable energy-powered systems is that exhaust gases do not contain hydrocarbon emissions. When all the results are evaluated together, it is seen that different approaches can be developed for the use of renewable energies in cooling systems, and they can be successfully applied in terms of thermodynamics.

The absorption cooling cycle considered for district cooling in has been successfully combined with the organic Rankine cycle for electricity generation. The unit cooling and electricity cost is calculated as 0.074 $/kWh and 0.017 $/kWh, respectively. This study proved that it is technically and cost-effectively possible to integrate power generation and space cooling into a system. The next stage of this study is to find the optimum operating conditions for the system by optimizing the system. As a result, it is expected that the cooling and power production of the system will increase, and the cost of unit cooling and electricity produced will decrease.

The study results will be beneficial for researchers interested in the variation of different operating temperatures on energy and exergy costs, as well as improving the sustainable energy demand.

Declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

Author Contributions

C. Yilmaz developed the methodology. O. Sen performed the analysis. C. Yilmaz and O. Sen wrote the manuscript together.

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Nomenclature

$\dot{C}$: Cost rate associated with exergy [\$/h]

$\dot{E}x$: Exergy rate [kW]

i : Interest rate [%]

$\dot{m}$: Mass flow rate [kg/s]

n : Operating period

$\dot{Q}$: Heat energy [kW]

T : Temperature [ºC]

$\dot{W}$: Power [kW]

$\dot{Z}$: Equipment cost rate [\$/h]

η : Energy efficiency

ε : Exergy efficiency

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