

Article

Investigation of Energy and Exergy of Geothermal Organic Rankine Cycle

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Abstract: In this study, modeling and thermodynamic analysis of the combined double flash geothermal cycle generation was conducted using zeotropic fluid as the working fluid in the Organic Rankine Cycle (ORC). The analysis was performed based on the first and second laws of thermodynamics. Hexane, cyclohexane, isohexane, R245fa, and R236ea exhibit good performance at higher temperatures. In this study, three fluids—hexane, cyclohexane, and isohexane—were used. First, the model results for the pure fluids were compared with those of previous studies. Then, the important parameters of the cycle, including the efficiency of the first law of thermodynamics, the efficiency of the second law of thermodynamics, net productive power, and the amount of exergy destruction caused by changing the mass fraction of the refrigerant for the zeotropic fluids (investigated for the whole cycle and ORC), were obtained and compared.

Keywords: energy efficiency; sustainable development; thermodynamic analysis; energy production



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1. Introduction

The global electricity demand is still increasing, and it is predicted that the demand will increase by 35% by 2035 [1]. In addition, concerns about the environmental effects of energy generation from fossil fuels, such as geothermal effects, ozone layer destruction, and the harmful effects of generation emissions, encourage researchers and industries to use clean renewable energy sources. Moreover, due to the dwindling supply of fossil fuel resources, many researchers are focusing on the development of renewable energy sources, including design and fabrication of automatic single-axis solar trackers for solar panels [2]. An experimental and comparative study on engine emissions of conventional diesel engines and dual fuel engines has also been conducted [3]. Geothermal energy is one of the renewable and clean energy sources that has received special attention since 1995 [4]. Because geothermal energy is a low-temperature energy source, power generation cycles such as the ORC are used for the proper utilization of this type of energy [5]. Among the cycles that have received special attention in recent years is the flash cycle, in which steam is separated from hot water by a separator. The steam generates power in a steam turbine and the hot water provides the energy needed to generate power in the ORC [6]. Despite the simplicity, flexibility, and high reliability of ORCs, one of the basic problems of these types of cycles is the high rate of exergy destruction. The main source of this

destruction is the cycle evaporator, which evaporates in this part of the working fluid cycle by receiving energy [7]. The main cause of exergy destruction in the evaporator is the temperature difference between the heat source and the temperature of the working fluid, which, according to the second law of thermodynamics, causes irreversibility and increases exergy destruction.

Using zeotropic fluids instead of normal fluids reduces exergy and improves system performance. Zeotropic fluids are a chemical mixture of different pure fluids that have different thermodynamic properties (exergy, entropy, and enthalpy) according to the type and amount of combined fluids. One of the most important properties of this type of fluid is the temperature glide between the saturated liquid and saturated vapor at a certain pressure, which leads to a decrease in temperature difference between the heat source and the working fluid. For pure working fluids, this temperature difference is equal to zero [8]. Several studies have been conducted in recent years on the use of zeotropic fluids in ORCs. Meng et al. presented a study whose goal was to produce hydrogen from renewable energy sources, using biomass sources as a stimulus for the production of electrical and thermal energy [9]. Mahmoudan et al. conducted a study with the aim of producing electric and thermal energy and hydrogen from geothermal and solar sources. To achieve this goal, exergy and energy analyses were conducted. In this research, the electrolyzer PEM was used to produce hydrogen, and the results showed that the studied system can produce 19 kg/h of hydrogen, with an exergy efficiency of 35.2% [10]. Ma et al. presented a hybrid renewable energy study. Research aimed at studying the effect of the storage system in supplying the required energy has also been presented. The studied system includes geothermal resources with the Organic Rankine Cycle, which has been thermodynamically modeled to achieve the goal of the study [11]. The use of zeotropic working fluid in an ORC to recover waste heat from a large diesel engine was presented by Kolahi et al. They concluded that the combination of cyclohexane and R236ea fluids with a ratio of 0.4 to 0.6 showed the best performance, with energy and exergy efficiencies of 14.57% and 37.84%, respectively [12]. The effect of 10 different groups of zeotropic working fluids on the performance of an ORC was analyzed by Kang et al. [13], where the R245fa–R600a mixture with a ratio of 0.1 to 0.9 was selected as the best working fluid among the proposed fluids. Deethayat et al. [14] investigated the operation of a low-temperature ORC with zeotropic fluids as the working fluid. They were able to provide a model for predicting the energy efficiency of the system by defining a dimensionless parameter called the merit number. The performance of an ORC using a zeotropic working fluid to set up an osmosis desalination system was investigated by Geng et al. [15]. According to their results, for the R600a–R601a combination, the molar ratio of 0.1/0.9 leads to the generation of the greatest power, with a value of 9.30 kW, which is used to start the desalination unit.

Zhang et al. investigated power, cooling, freshwater, and hydrogen production systems from geothermal energy. The purpose of this research was to reduce the cost of the studied system by increasing power production. For this purpose, exergy and energy analyses were conducted, and the results showed that in the optimal case, the investment return rate is equal to 3.76 years [16]. The economic performance of an ORC system using a zeotropic mixture as the working fluid was investigated by Wu et al. Their results indicated that the best performance of the system can be achieved when the temperature difference of the cooling water in the condenser is close to the temperature glide of the zeotropic mixture in the condenser [17]. A partial evaporation ORC system with zeotropic fluid as the working fluid was investigated by Zhou et al. According to their results, the exergy degradation in the evaporator and condenser was significantly reduced after using zeotropic fluids as the working fluid [18]. Table 1 shows different research studies focusing on energy and exergy analyses of geothermal Organic Rankine Cycles.

Table 1. List of different research studies focusing on energy and exergy analyses of geothermal Organic Rankine Cycles.

Researcher	Method	Results
Zhao et al. [19]	Energy and exergy analyses	Increase in temperature absorbed by the system from 70 °C to 75 °C
Zhao et al. [20]	A hot dry rock power generation system model	Heat exchanger and the vapor separator were the weak components in the system, and they, respectively, contributed to 44.8% and 29.8% of the total exergy destruction
Norouzi et al. [21]	Designed to generate power and hydrogen	Energy and exergy efficiency and the amount of hydrogen produced in the system were equal to 101.2 kW, 82.3%, 81.0%, and 4.239 L/s, respectively
Zinsalo et al. [22]	Multi-objective optimization	Increase in the energy and exergy efficiency by the system to 0.2%
Sreekanth et al. [23]	Load performance study	Increase in the exergy efficiency by the system to 11.9%
Kim et al. [24]	Thermodynamic analyses	Thermal efficiency and second-law efficiency were 10–27% and 11–18%, respectively
Nourpour et al. [25]	Exergy, exergoeconomic, emergoeconomic, and emergoenvironmental (6E) analyses	Increase in power generation by the system to 21 MW
Altayib et al. [26]	Integration of solar thermal energy with geothermal for improved power generation efficiency	Increase in overall exergy efficiency

When reviewing the research to date, it can be concluded that appropriate research has not yet been conducted on the use of zeotropic fluids in the two cycles, and more research is needed.

In this research, the goal was to increase net power production along with the reduction in exergy destruction, and to achieve this purpose, energy and exergy analyses were applied. The working fluid in this research is a combination of three hydrocarbons—hexane, cyclohexane, and isohexane—with two refrigerants: R245fa and R236ea.

2. Materials and Methods

Due to the challenges associated with fossil fuels and environmental crises faced today, the use of geothermal energy as a renewable energy source can be useful. Since the two wells used at the Sabalan geothermal power plant have different thermodynamics, in the present study, a new combined layout based on two flash cycles is proposed and investigated.

2.1. System Description

A diagram of the system is shown in Figure 1. Geothermal fluid (zeotropic fluid) pressure (point 1) is reduced by passing through the flash chamber (point 2) and then separated into two parts in the separator chamber: saturated steam (point 3) and saturated liquid (point 6). Saturated steam enters the steam turbine and its pressure is reduced to the condenser pressure, and the turbine generates electricity by connecting to the generator. The output of the turbine (point 4) is then condensed into the condenser (point 5). The saturated liquid exiting the separator chamber (point 6) enters a heat exchanger and uses its heat to start an ORC. Finally, the geothermal fluid, after passing through the heat exchanger and losing heat (point 7), is combined with the condensate outlet fluid (point 5) and returned to the ground (point 12).

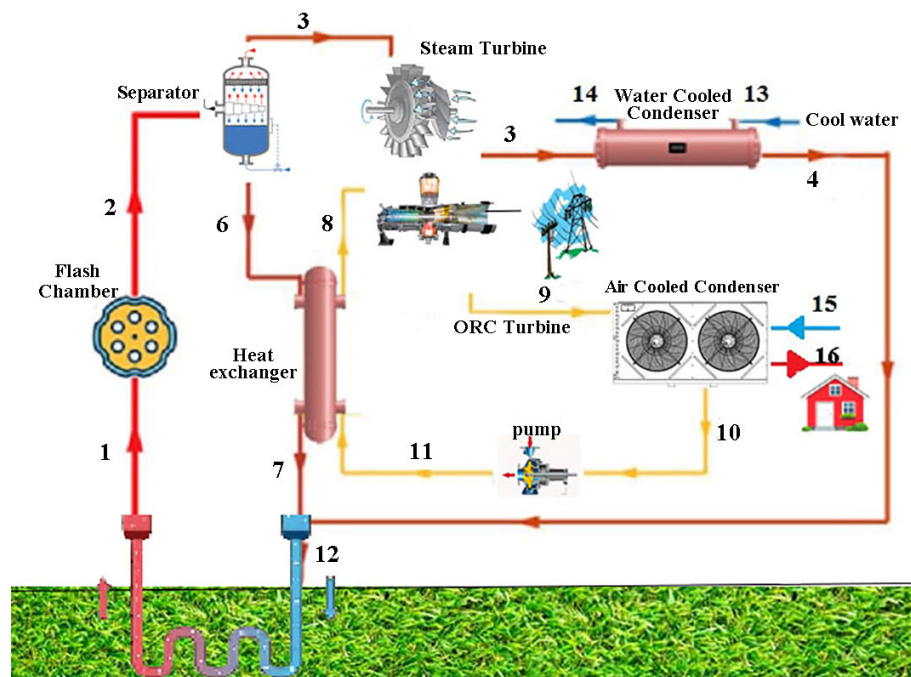


Figure 1. Geothermal system to produce heat and power.

The ORC, which uses zeotropic fluid, uses geothermal fluid heat in the heat exchanger to evaporate its working fluid. The zeotropic fluid, which consists of a combination of three hydrocarbons (hexane, cyclohexane, and isohexane) and two refrigerants (R236ea and R245fa), enters the turbine after evaporation (point 8). The turbine generates electricity by expanding and reducing the flow pressure by connecting to the generator. Then, this output flow from the turbine (point 9) is condensed in the condenser (point 10) and finally sent back to the heat exchanger by the pump (point 11). Figure 2 shows a T-s diagram of the ORC with zeotropic working fluid.

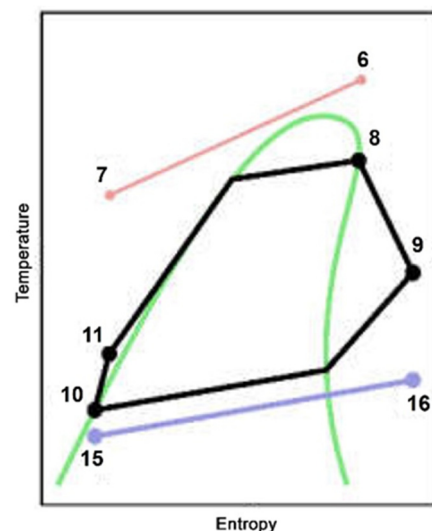


Figure 2. Geothermal system for heat and power generation.

The assumptions considered in this study are:

- The whole system works in a stable mode.
- The pressure drop in the connecting pipes, potential and kinetic energies, and heat loss in the system are ignored.

- The thermophysical properties of the geothermal fluid are the same as the thermophysical properties of pure water.
- The pressure and temperature of the dead state are equal to the pressure and temperature of the environment (25 °C, 1 atm).

The rest of the assumptions and information on the system are given in Table 2. Table 3 shows the properties of the five organic working fluids.

Table 2. Some assumptions and information used in system analysis [27–29].

Assumption	Value
Geothermal fluid mass flow rate	100 kg/s
Geothermal fluid temperature	200 °C
Pressure ratio in a steam turbine	60
Isentropic efficiency of turbines	0.85
Isentropic efficiency of the pump	0.85
Condenser inlet cooling water temperature	25 °C
Condenser inlet cooling water pressure	150 kPa
Pinch temperature difference in the evaporator	15 °C
Pinch temperature difference in the condenser	10 °C
Bubble temperature in the evaporator	100 °C
Dew point temperature in the condenser	75 °C

Table 3. Properties of the five organic working fluids.

Working Fluid	Molecular Weight (g·mol ⁻¹)	Normal Boiling Point (°C)	Critical Temperature (°C)	Critical Pressure (MPa)
Hexane	86.178	69	304.29	3.031
Cyclohexane	84.16	80.75	281	4.07
Isohexane	86.175	60.21	224.55	3.040
R245fa	134.048	15.14	154.01	3.651
R236ea	152.039	6.19	139.29	3.502

2.2. Thermodynamic Analysis

According to the first and second laws of thermodynamics and the law of conservation of mass [5,6], we can write:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

$$\dot{Q} + \dot{W} = \sum \dot{m}_{out} h_{out} - \sum \dot{m}_{in} h_{in} \quad (2)$$

$$\begin{aligned} \dot{E}x_Q + \sum_{in} \dot{m}e &= \sum_{out} \dot{m}e + \dot{W} + \dot{I}_D \\ \dot{I}_D &= \dot{E}x_Q - \dot{W} + \sum_{in} \dot{m}e - \sum_{out} \dot{m}e \end{aligned} \quad (3)$$

In these relationships:

$$\dot{E}_Q = \sum \dot{Q} \left(1 - \frac{T_0}{T} \right) \quad (4)$$

$$\dot{E} = \dot{m}e = \dot{m}(h - h_0 - T_0(s - s_0)) \quad (5)$$

Here, $\dot{m}$ is the mass flow rate, $\dot{Q}$ is the rate of heat transfer, $\dot{W}$ is the power, h is the enthalpy, s is the entropy, $\dot{E}$ is the exergy, $\dot{I}$ is the exergy destruction rate, and $\dot{E}_Q$ is the

net exergy transferred by heat transfer at temperature T . The relationships between the first and second laws of thermodynamics and the law of conservation of mass for each component of the system are detailed in Table 4.

Table 4. Relationships between the first and second laws of thermodynamics and the law of conservation of mass for each component of the system [9,30].

Component	Crime Survival	Energy Balance	Exergy Balance
Flash chamber	$\dot{m}_1 = \dot{m}_2$	$h_1 = h_2$	$\dot{E}_1 = \dot{E}_2 + \dot{E}_{D_V}$
Separator	$\dot{m}_2 = \dot{m}_3 + \dot{m}_6$	$\dot{m}_2 h_2 = \dot{m}_3 h_3 + \dot{m}_6 h_6$	$\dot{E}_2 = \dot{E}_3 + \dot{E}_6 + \dot{E}_{D_{Sep}}$
Steam turbine	$\dot{m}_3 = \dot{m}_4$	$\dot{m}_3 h_3 = \dot{m}_4 h_4 + \dot{W}_{ST}$	$\dot{E}_3 = \dot{E}_4 + \dot{W}_{ST} + \dot{E}_{D_{ST}}$
Condenser 1	$\dot{m}_4 = \dot{m}_5$	$\dot{m}_4 h_4 + \dot{m}_{13} h_{13} = \dot{m}_5 h_5 + \dot{m}_{14} h_{14}$	$\dot{E}_4 + \dot{E}_{13} = \dot{E}_5 + \dot{E}_{14} + \dot{E}_{D_{C1}}$
Heat exchanger	$\dot{m}_6 = \dot{m}_7, \dot{m}_{11} = \dot{m}_8$	$\dot{m}_6 h_6 + \dot{m}_{11} h_{11} = \dot{m}_8 h_8 + \dot{m}_7 h_7$	$\dot{E}_6 + \dot{E}_{11} = \dot{E}_8 + \dot{E}_7 + \dot{E}_{D_{HE}}$
ORC turbine	$\dot{m}_8 = \dot{m}_9$	$\dot{m}_8 h_8 = \dot{m}_9 h_9 + \dot{W}_{CT}$	$\dot{E}_8 = \dot{E}_9 + \dot{W}_{CT} + \dot{E}_{D_{CT}}$
Condenser 2	$\dot{m}_9 = \dot{m}_{10}$	$\dot{m}_9 h_9 + \dot{m}_{15} h_{15} = \dot{m}_{10} h_{10} + \dot{m}_{16} h_{16}$	$\dot{E}_9 + \dot{E}_{15} = \dot{E}_{10} + \dot{E}_{16} + \dot{E}_{D_{C2}}$
Pump	$\dot{m}_{10} = \dot{m}_{11}$	$\dot{m}_{10} h_{10} + \dot{W}_P = \dot{m}_{11} h_{11}$	$\dot{E}_{10} + \dot{W}_P = \dot{E}_{11} + \dot{E}_{D_P}$

The efficiency of the first and second laws for the discussed system is defined as follows [5,6]:

$$\eta_1 = \frac{\dot{W}_{net}}{\dot{Q}} \quad (6)$$

$$\eta_{11} = \frac{\dot{W}_{net}}{\Delta \dot{E}} \quad (7)$$

In ORC [9,31]:

$$\dot{W}_{net} = \dot{W}_{CT} - \dot{W}_P \quad (8)$$

$$\dot{Q} = \dot{m}_6 h_6 - \dot{m}_7 h_7 \quad (9)$$

$$\Delta \dot{E} = \dot{m}_6 e_6 - \dot{m}_7 e_7 \quad (10)$$

Then, for the whole system [8,9]:

$$\dot{W}_{net} = \dot{W}_{ST} + \dot{W}_{CT} - \dot{W}_P \quad (11)$$

$$\dot{Q} = \dot{m}_1 h_1 - \dot{m}_{15} h_{15} \quad (12)$$

$$\Delta \dot{E} = \dot{m}_1 e_1 - \dot{m}_{15} e_{15} \quad (13)$$

It should be noted that the thermodynamic properties of zeotropic fluids were obtained for different concentrations of pure fluid in the mixture using Refprop software.

2.3. Validation

The work of Yilmaz et al. [27] was used to validate the obtained results regarding the geothermal cycle. In the case of the ORC, the work of Shu et al. [28] was used for validation of the cyclohexane/R123 compound fluid with a mass ratio of 0.3–0.7 components. Table 5 shows a comparison of the present work and reference [27], and Table 6 shows a comparison of the present work and reference [28]. As shown, the differences between the results in the two articles are minor, caused by the different software used for the calculations.

Table 5. The results of the present work are based on the work of Yilmaz et al. [27].

Point	Fluid	Results	Mass Flow Rate (kg/s)	Temperature (°K)	Pressure (kPa)	Enthalpy (kJ/kg)	Entropy (kJ/kg K)
2	Geothermal	Results [27]	100	431	600	852.3	2.352
		Present results	100	432	600	852.27	2.3519
5	Geothermal	Results [27]	8.72	318	10	191.8	0.6492
		Present results	8.72	39	10	191.81	0.6492
8	Organic fluid	Results [27]	60.79	421	2100	802.7	2.689
		Present results	60.75	422	2100	801.86	2.686
11	Organic fluid	Results [27]	60.79	303	2100	274.5	1.246
		Present results	60.75	304	2100	273.88	1.2442

Table 6. Comparing the overall results of this study with those of Shu et al. [28].

Symbol	Reference [26]	Present Work	Difference (%)
$\dot{Q}$ (kW)	124.96	124.84	0.10
η_1	13.73	13.69	0.29
η_{11}	32.12	32.02	0.31

3. Results

Figures 3–6 show the obtained results. In these diagrams, the desired parameters are presented based on the changes in the mass fraction of the zeotropic fluid. Figure 3 shows the changes in the efficiency of the first law for the whole system and the ORC with the change in the refrigerant mass fraction. As can be seen from the graphs, with the increase in the mass fraction of refrigerants (that is, R236ea and R245fa) in the zeotropic composition, the efficiency of the first law first increases and then decreases. The reason for this behavior should be sought in the temperature behavior of zeotropic fluids in the two-phase state: the phase change of zeotropic fluids at constant pressure does not occur at a constant temperature and a temperature jump occurs during this phase change (Figure 2). The level of this temperature jump, which represents the temperature difference between saturated vapor and saturated liquid at a certain pressure, increases with mass fraction. The refrigerant in the composition first increases and then decreases. That is why the phase change of both fluids in the composition does not occur at the same time as the increase (or decrease) of heat in the two-phase state [12]. Despite this temperature behavior, there is an increase in the average temperature at which evaporation occurs of the ORC in the heat exchanger (the evaporator of this cycle) (points 11 to 8), and the condensing temperature of the average ORC in the condenser (points 9 to 10) decreases. There is also a better match between the temperature profiles of the working fluid and the fluid in the heat sources (evaporator and condenser). Since the best temperature matching in the evaporator and condenser occurs in medium mass fractions, the lowest exergy destruction also occurs in this range, and the system shows the best performance. All these factors cause the ascending–descending behavior in the charts. According to Figure 3, the highest efficiency value of the first law is related to the working fluid, cyclohexane/R236ea, with a mass fraction of 0.6 for the refrigerant, which is equal to 15.15% for the whole system and 10.61% for the ORC.

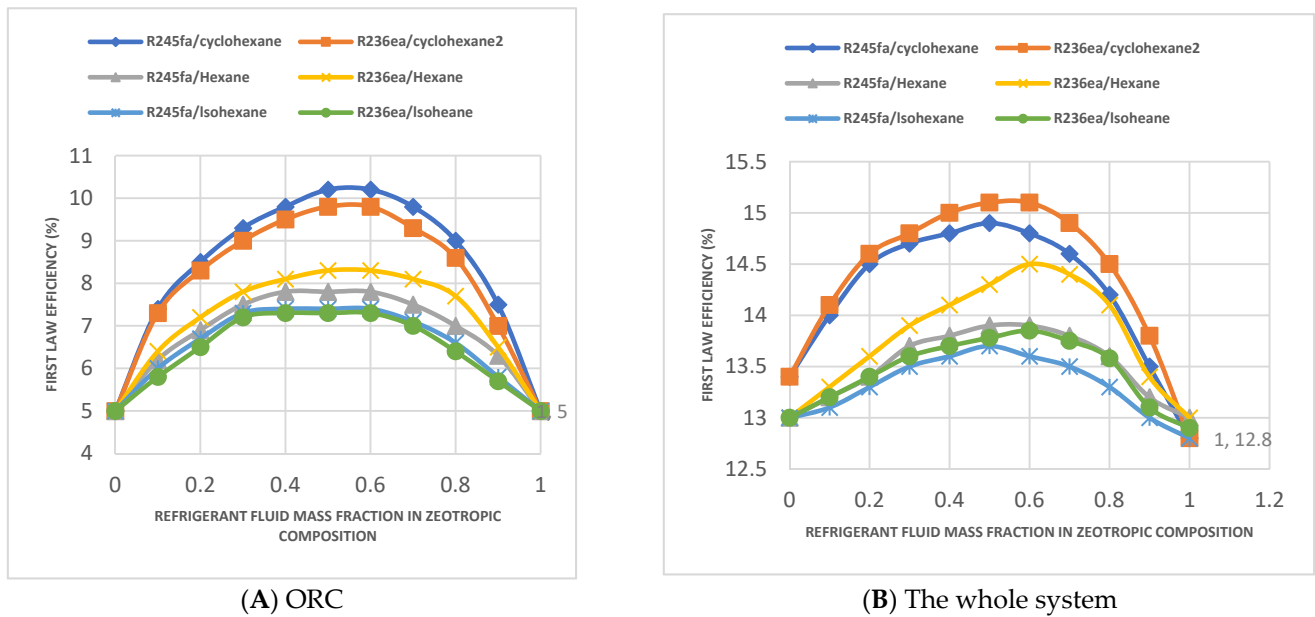


Figure 3. The efficiency of the first law of the whole system and the ORC to the mass fraction of refrigerants in the zeotropic composition.

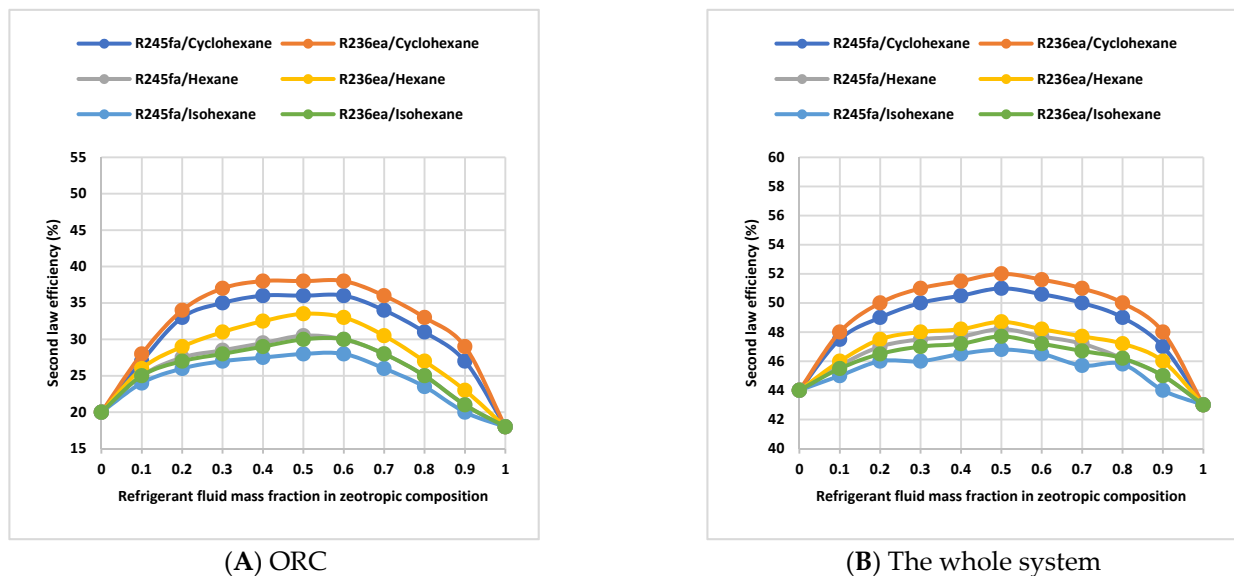


Figure 4. The efficiency of the second law of the whole system and the ORC to the mass fraction of refrigerants in the zeotropic composition.

The changes in the efficiency of the second law for the whole system and the ORC with a change in the mass fraction of refrigerants are presented in Figure 4. In these graphs, for the same reasons mentioned for the first law of thermodynamics, the efficiency of the second law first increases and then decreases with the increase in the mass fraction of refrigerants, and the highest values of the efficiency of the second law in the entire system and ORC are 53.21% and 42.30%, which are obtained for the working fluid cyclohexane/R236ea with a mass fraction of 0.6 for the refrigerant.

Figure 5 shows the net productive power of the whole system and the Organic Rankine Cycle. As is clear from the graphs, the amount of generated power maintains its ascending–descending behavior with the increase in the mass fraction of refrigerants. The important point is the increase in total net productive power (for example, from about 6.5 MW to about 7 MW for cyclohexane/R245fa zeotropic fluid), which indicates a significant increase

in power generation in zeotropic fluid compared to pure fluid (with mass fraction 0 or 1). In the graphs, the highest values of the net power generated for the working fluid cyclohexane/R236ea with a mass fraction of 0.6 for the refrigerant are 3.74 MW for the ORC and 7.31 MW for the whole system.

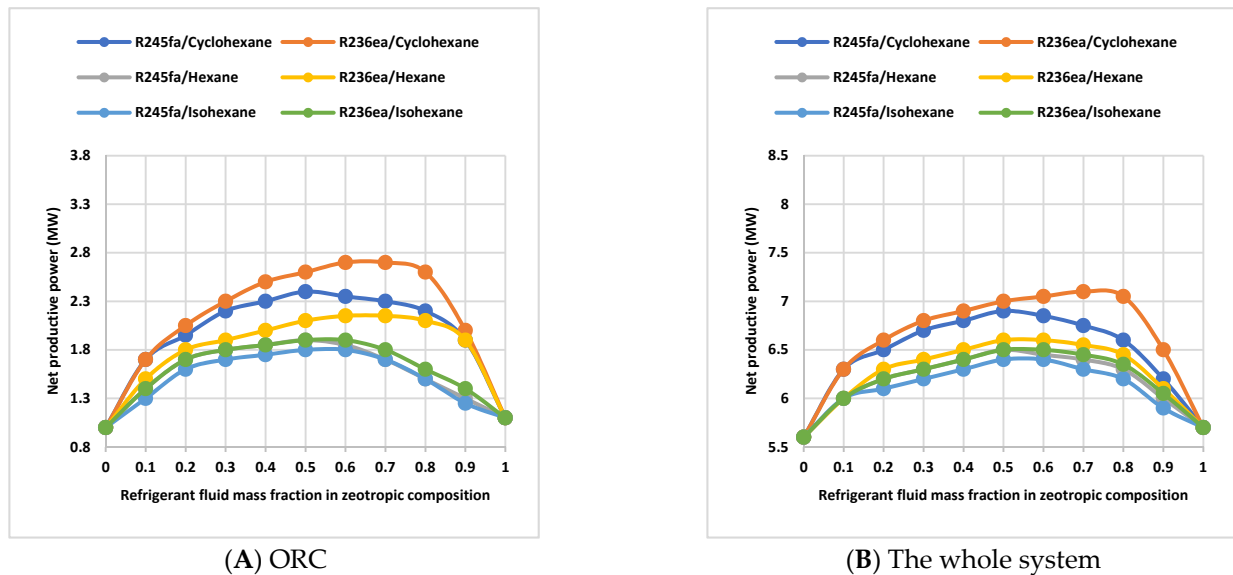


Figure 5. The net productive power of the whole system and the ORC to the mass fraction of refrigerants in the zeotropic composition.

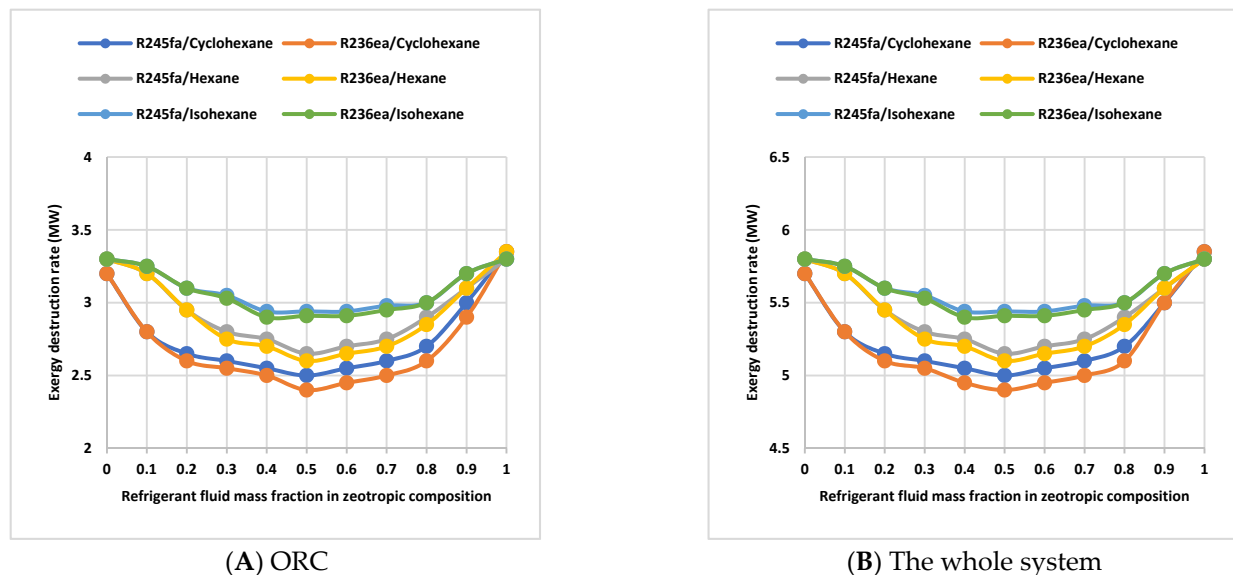


Figure 6. The destructive rate of exergy in the whole system and the ORC to the mass fraction of refrigerants in the zeotropic composition.

As can be seen from Figure 5A, the maximum net power produced is related to refrigerant cyclohexane/R236ea with a mass fraction of 0.7, the amount of net power produced by the ORC is 2.73 MW, and the minimum net power produced is related to refrigerant R245fa/isohexane, with the amount of net power produced by the ORC being 0.95 MW. As can be seen from Figure 5B, the maximum net power produced is related to refrigerant cyclohexane/R236ea with a mass fraction of 0.74, the amount of net power produced by the whole system is 7.15 MW, and the minimum net power produced is related to refrigerant R245fa/isohexane, with the amount of net power produced by the whole

system being 5.64 MW. The exergy destruction rates for the whole system and the ORC are presented in the graphs in Figure 6.

As mentioned in the introduction section, one of the most important advantages of zeotropic fluids is reducing the temperature difference between the heat source and the working fluid in the evaporator, which is the largest entropy generator in the Organic Rankine Cycle. The maximum temperature match between the heat source and the working fluid occurs in medium mass fractions, i.e., from about 0.4 to 0.6, which leads to the reduction in exergy destruction, according to Figure 6, in this range. As can be seen from Figure 6, the lowest values of exergy destruction that occur in the working fluid cyclohexane/R236ea with a mass fraction of 0.6 for the refrigerant are 2.34 MW in the ORC and 4.79 MW in the whole system.

According to the obtained results, the zeotropic working fluid cyclohexane 0.4/R236ea 0.6 has the best performance among the proposed fluids. In Table 7, the thermodynamic properties of all points of the system, along with the mass flow rate and flow exergy rate of those points, are presented for this zeotropic working fluid.

Table 7. Thermodynamic properties, mass flow rate, and exogenous rate of system points for cyclohexane 0.4/R236ea 0.6.

Point	Fluid	Mass Flow Rate (kg/s)	Temperature (°K)	Pressure (kPa)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)	Exergy (kJ/kg)
1	Geothermal	100	473	1555	852.27	2.3305	161.98
2	Geothermal	100	431	600	852.27	2.3519	155.61
3	Geothermal	8.72	431	600	2756.14	6.7592	745.43
4	Geothermal	8.72	318	10	2232.97	7.0487	135.96
5	Geothermal	8.72	318	10	191.81	0.6492	2.81
6	Geothermal	91.28	431	600	670.38	1.9308	99.26
7	Geothermal	91.28	365	600	386.94	1.2185	28.19
8	Organic fluid	70.88	417	902.12	472.81	1.5771	76.98
9	Organic fluid	70.88	376	152.46	433.26	1.5958	31.87
10	Organic fluid	70.88	303	152.46	106.95	0.6054	0.85
11	Organic fluid	70.88	304	902.13	107.79	0.6058	1.56
12	Geothermal	10	361	65.53	369.92	1.1732	24.68

4. Conclusions

The use of geothermal energy for the combined production of heat and electricity is welcome, and in areas where the ground gradient is suitable, the construction of a geothermal power plant to produce electrical energy with power cycles is a good option to replace fossil power plants. However, due to the low heat production, geothermal power plants are less efficient than other power plants; therefore, this article has evaluated the effect of fluids on the efficiency of geothermal power plants and analyzed exergy with the aim of increasing efficiency. In the studied system, the effect of fluids consisting of the hydrocarbons hexane, cyclohexane, and isohexane and the refrigerants R254fa and R236ea on energy efficiency and exergy destruction has been evaluated. The amount of net power received, work produced, and energy waste based on different working fluids has also been calculated. According to the obtained results, it can be stated that:

- The total energy efficiencies of the system and Organic Rankine Cycle increase with the increase in the mass fraction of the refrigerant fluid in the geotropic composition, but after a mass fraction of 0.6, they decrease until the total efficiencies of the system and Organic Rankine Cycle are 13% and 3%, respectively.

- Due to the constant temperature and flow rate of geothermal feed water, an increase and decrease in the efficiencies of the first and second laws of thermodynamics occur due to an increase and decrease in the net power output. As a result, the net power output shows behavior similar to thermodynamic efficiencies. For that reason, changing the mass fraction of the zeotropic fluid does not affect the generation power of the steam turbine, with only the generation power of the ORC changed. According to the obtained results, the highest amount of improvement in the power of the ORC is for the cyclohexane/R236ea working fluid, which is about 1.9 MW.
- As mentioned, one of the most important advantages of zeotropic fluids is the reduction in exergy destruction in the ORC evaporator due to the reduction in temperature difference between the heat source and the working fluid. According to the obtained results, the greatest reduction in exergy destruction occurs in medium mass ratios where there is the greatest temperature match between the heat source and the working fluid. The best working fluid is cyclohexane/R236ea with a mass fraction ratio of 0.6 to 0.4.

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Abbreviations

$\dot{m}$	Mass flow rate (kg/s)
$\dot{Q}$	Heat transfer (kW)
$\dot{W}$	Power (kW)
h	Enthalpy (kJ/kg)
S	Entropy (kJ/kg K)
$\dot{E}$	Exergy (kJ/kg)
$\dot{I}$	Exergy destruction rate
$\dot{E}_Q$	Net exergy transferred by heat transfer (kW)
T	Temperature (°K)
P	Pressure (kPa)
η_I	First-law efficiency
η_{II}	Second-law efficiency

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