

Article

Performance Analysis and Parametric Analysis of the Organic Rankine Cycle Considering Seasonal Temperature Variations

Yaohui Yang, Liwen Zhao  and Guilian Liu *

School of Chemical Engineering and Technology, Xi'an Jiaotong University, Xi'an 710049, China

* Correspondence: guilianliu@mail.xjtu.edu.cn

Abstract

Under the “dual carbon” strategy, the organic Rankine cycle (ORC) represents a key technology for efficiently recovering low-grade industrial waste heat in inland factories. This study addresses ORC operational instability caused by seasonal temperature fluctuations and high cooling-water costs in inland regions. An ORC system powered by industrial waste heat is investigated. A steady-state simulation model is developed in Aspen Plus to analyze the effects of expansion pressure, condensation pressure, cooling-water flow rate, and working-fluid flow rate on system performance, and to filtrate parameters to maximize economic returns. The results demonstrate that optimal expansion pressure yields maximum net shaft power. Condensation pressure and the cooling-water flow rate are closely linked, necessitating a balance between power generation revenue and cooling costs. An optimal range for working-fluid flow rate is also identified. Seasonal temperature variations significantly influence system performance. Higher summer temperatures increase condensation pressure and reduce revenue, while lower winter temperatures enhance revenue when filtrated parameters are used. This research provides theoretical and technical references for achieving efficient, cost-effective, year-round ORC operation in inland factories. In the case study, the analysis for seasonal temperature variations increases the total annual revenue by CNY 2.217 million, with an annual average system efficiency of 10.59%.

Keywords: organic Rankine cycle; seasonal temperature changes; cooling water flow rate; cycle working fluid flow rate; economic benefits

1. Introduction

Achieving carbon peaking and neutrality requires efficient recovery and the use of low-grade waste heat in industry. The organic Rankine cycle (ORC) effectively utilizes low-temperature heat between 80 and 200 °C, offers a compact design, and operates reliably. ORC is a key technology for waste-heat power generation and cascade energy use in chemical, metallurgical, and building material industries [1]. Unlike traditional steam Rankine cycles, ORCs use low-boiling organic fluids and maintain high expander efficiency at low temperatures, making them well-suited for distributed industrial waste heat [2]. ORC technology has been widely researched and applied in industrial waste heat, geothermal, and solar energy, demonstrating strong potential for future adoption [3].

Seasonal fluctuations in ambient temperature are significant in inland regions and directly impact cooling-water temperature and condenser heat exchange. These fluctuations have a substantial impact on the operating parameters and economic performance of ORC systems [4]. Additionally, variations in heat-source temperature and flow rate affect



Academic Editors: Lorenzo Miserocchi and Alessandro Franco

Received: 8 June 2026

Revised: 13 July 2026

Accepted: 14 July 2026

Published: 16 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

evaporation pressure, superheat, and shaft work. For inland factories that use circulating cooling water as the cold source, temperature-driven changes in the cooling-water flow rate and energy consumption further increase uncertainty in the system's economic benefits.

Li et al. [5] found that R1234ze (E) is the most effective fluid for ORC performance across various heat-exchanger materials, while R245fa showed the lowest thermal-economic performance in some cases. Hu et al. [6] determined that R1234ze (E) also provides the highest thermodynamic performance among seven hydrogen fluoride olefins. Johan et al. [7] reported that a mixture of n-pentane and R1233zd achieved the highest coefficient of performance. Max et al. [8] concluded that R717 is well suited for tropical climates in a novel cogeneration system that combines an ORC, a vapor absorption cycle (VAC), and a vapor compression cycle (VCC). Montaser et al. [9] demonstrated that lowering the condensation temperature from 25 °C to 15 °C at a 3 MPa expander inlet pressure increased the net output power for R123, R124, and R245fa by 7.35%, 12.13%, and 8.77%, respectively. Samet et al. [10] used the multi-objective grey wolf algorithm to optimize design conditions and selected R245fa as the preferred working fluid. Wang et al. [11] showed that R245fa/R600 and R600/R600a mixtures outperformed other fluids using a multi-attribute evaluation model. Wan Ramli et al. [12] found that R600a delivered the best thermal efficiency, net power, and irreversibility reduction among several working fluids under varying conditions. Ding et al. [13] applied a genetic algorithm for multi-objective optimization and identified R245fa as the top performer in a specific ORC system. Hu et al. [14] illustrated that R245fa maximized net power generation per unit mass of geothermal water.

Xu et al. [15] compared subcritical and supercritical cycles using R1234ze (E) as the working fluid. Although supercritical cycles yielded lower economic returns, they improved cycle thermal efficiency and increased maximum net output power by 18.2%. Yang et al. [16] employed a multi-objective genetic algorithm to optimize system performance and parameters, identifying critical temperature as the main factor affecting system performance. Imre et al. [17] examined how critical temperature and cyclic structure influence output parameters, noting that the effect depends on the working fluid. Li et al. [18] found that higher mass flow rates in ORC systems for LNG engine energy recovery increase pressure drop and reduce direct-expansion efficiency. He et al. [19] developed a simulation optimization method using the particle swarm algorithm that enables the real-time automatic selection of mixed working-fluid types and proportions in an ORC system. This method improved the efficiency of cold energy generation in the middle-temperature section, increasing net power output by 22.48% and round-trip efficiency to 141.88%.

Recent studies have optimized working fluids such as R245fa, R236f, and R134a using multi-objective evaluation methods [20]. Researchers have examined how evaporation temperature, evaporation pressure, and condensation temperature affect system thermal efficiency, net power generation, and exergy efficiency [21–23]. These studies demonstrate that operating parameters significantly affect system power generation and efficiency [24–26]. However, most research has focused on optimizing thermal or exergy efficiency, with limited consideration of cooling-water cost and economic benefits in a unified optimization framework [27–29]. Furthermore, few studies address the combined effects of operating parameters under varying environmental conditions or investigate economically optimal regulation.

This study examines how ambient temperature affects the performance of cooling water in ORC systems [30–32], with a focus on industrial waste heat recovery at an inland factory. The analysis assesses the impact of expansion pressure, condensation pressure, cooling-water flow rate, and working-fluid flow rate on system performance. Parametric analysis prioritizes economic benefit, providing theoretical guidance and technical support for efficient, stable, and cost-effective ORC operation in inland factories. Unlike previous

ORC optimization studies that rely on assumed operating conditions and theoretical cost functions [4,5,14,20], this work introduces a plant-data-driven parametric screening framework that incorporates seasonal weather variations and site-specific empirical cost correlations. The framework uses a full-factorial enumeration approach, providing a practical advantage over heuristic algorithms by mathematically ensuring global optimality within the feasible parameter space.

2. System Characteristics

The ORC uses a low-boiling organic working fluid to convert low-grade industrial waste heat into electricity through a closed-loop cycle of pressurization, heat absorption and evaporation, expansion, and condensation. The main components, including the evaporator, expander, condenser, and working-fluid pump, enable energy transfer and conversion. The principle is shown in Figure 1. System performance and economic benefits depend on the interaction of key parameters.

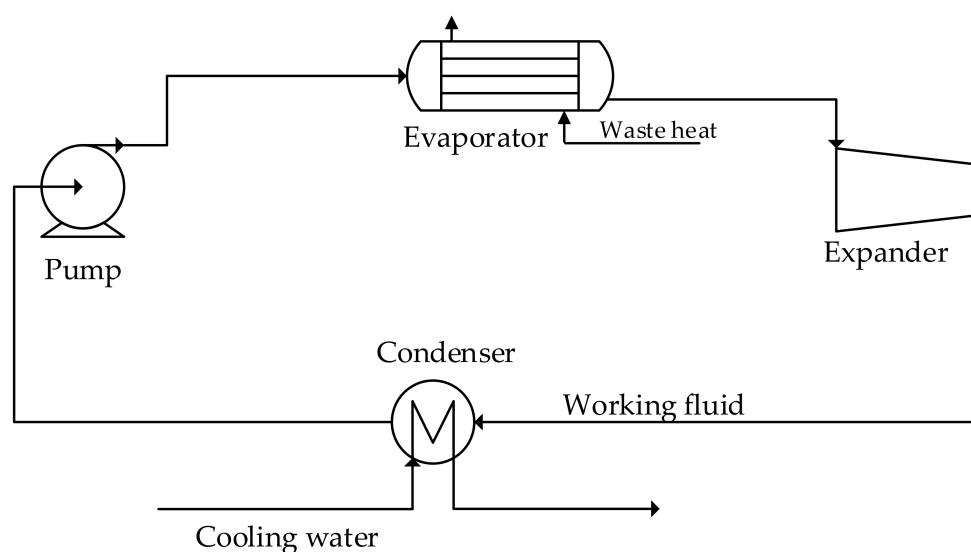


Figure 1. Schematic diagram of organic Rankine cycle system.

The evaporator transfers thermal energy from industrial waste heat to the organic working fluid, as shown in Equation (1). Superheated steam then enters the expander, where it performs work, with the actual output calculated by Equation (2).

$$Q_{evap} = Q_h \times \eta_{evap} \quad (1)$$

$$W_{expander} = m \times (h_{exp,in} - h_{exp,out}) \quad (2)$$

where Q_{evap} and Q_h denote the heat absorbed by the working fluid and the amount of waste heat, respectively; η_{evap} represents the heat exchange efficiency of the evaporator; $W_{expander}$ indicates the actual output work of the expander (kW); m refers to the mass flow rate of the working fluid (kg/s); and $h_{exp,in}$ and $h_{exp,out}$ denote the enthalpy at the inlet and outlet of the expander (kJ/kg), respectively.

The expanded organic working fluid enters the condenser, where it changes phase and releases heat, as described by Equation (3). Following condensation, the low-temperature fluid is pumped to the evaporation level, increasing its pressure. The fluid then returns to the evaporator, completing the organic Rankine cycle. The power consumption of the working-fluid pump is shown in Equation (4).

$$Q_{cond} = m \times (h_{cond,in} - h_{cond,out}) \quad (3)$$

$$W_{pump} = m \times (h_{pump,out} - h_{pump,in}) / \eta_{pump} \quad (4)$$

where Q_{cond} represents the heat released by the working fluid; $h_{cond,in}$ and $h_{cond,out}$ correspond to the enthalpy at the inlet and outlet of the condenser (kJ/kg), respectively. W_{pump} specifies the power consumption of the working fluid pump; $h_{pump,out}$ and $h_{pump,in}$ represent the enthalpy at the outlet and inlet of the streams to the working fluid pump (kJ/kg), respectively; and η_{pump} represents the efficiency of the working fluid pump.

The net shaft power of the organic Rankine cycle system is shown in Equation (5). Equations (6) and (7) present the thermal efficiency and the revenue, respectively.

$$W_{net} = W_{expander} - W_{pump} = m \times (h_{exp,in} - h_{exp,out} - \frac{h_{pump,out} - h_{pump,in}}{\eta_{pump}}) \quad (5)$$

$$\eta_{ORC} = W_{net} / Q_{evap} = \frac{(h_{exp,in} - h_{exp,out} - \frac{h_{pump,out} - h_{pump,in}}{\eta_{pump}})}{(h_{exp,in} - h_{pump,out})} \quad (6)$$

$$P = 0.55W_{net} - 0.001m_{cw} - 1.5 \times 10^{-11}m_{cw}^3 \quad (7)$$

where P denotes the system revenue, in 10^4 CNY/year; and m_{cw} denotes the flow rate of the circulating cooling water (kmol/h). The income equation is based on operational data from the target industrial facilities. The coefficients are as follows: 0.55 for net shaft power (10^4 CNY/(kW·h)), 0.001 for cooling-water unit cost (10^4 CNY/kmol), and 1.5×10^{-11} for equipment power consumption (10^4 CNY·h²/kmol³).

In this model, economic coefficients such as electricity price and cooling-water unit cost are represented as annual time-weighted averages. This approach allows the analysis to focus on the thermo-economic relationship between power output and cooling-water flow rate. Seasonal variations in cooling-water temperature are fully addressed in the parametric analysis in Sections 4 and 5.

The working-fluid flow rate directly influences total heat absorption. Increasing flow rate raises expander output, but excessive flow significantly increases pump power consumption. Raising evaporation pressure increases $h_{exp,in}$, while lowering condensation pressure decreases $h_{exp,out}$. Both actions widen the enthalpy difference and boost output work. However, higher evaporation pressure or lower condensation pressure also increase pump power consumption. Typically, there is an optimal evaporation pressure that maximizes net shaft output.

3. Parametric Analysis Model Considering Cooling-Water Temperature Variation

In an organic Rankine cycle system, the main adjustable parameters are the expansion pressure, the condensation pressure, the cooling-water flow rate, and the working-fluid flow rate. MATLAB R2025a serves as the master program, sequentially calling Aspen Plus V12 through the ActiveX interface to evaluate all combinations of these parameters at defined step sizes within their feasible ranges. Revenue is calculated for each working condition, and the combination that produces the highest revenue is selected as the optimal operating point. This exhaustive search ensures the global optimum within the specified bounds, given the deterministic and low-dimensional nature of the steady-state model.

Under steady operating conditions, increasing the expansion pressure raises the heat absorption temperature, the evaporator inlet enthalpy, and the pressure difference across the expander, thereby improving output work. However, it also increases the working-fluid pump's power consumption. Excessively high expansion pressure reduces the working fluid's superheat and may affect expander stability. Conversely, an excessively low expansion pressure reduces the expansion ratio and work capacity, thereby reducing net shaft power and cycle efficiency. Therefore, analyzing expansion pressure under steady-state conditions maximizes net shaft power and efficiency.

Under steady operating conditions, increasing the condensation pressure reduces the expander's expansion ratio and work capacity per unit mass, resulting in lower net shaft and thermal efficiency. The working-fluid pump's power consumption rises slightly. Lowering the condensation pressure increases the cycle's work capacity, improving efficiency and net shaft power. However, excessively low condensation pressure may prevent the working-fluid from fully condensing. To avoid non-liquid working fluid and potential pump surges, the cooling-water flow rate increases. Higher cooling-water flow improves heat transfer, reduces condensation temperature and pressure, increases the expansion ratio, and raises net shaft power. These advantages must be balanced against the higher cost and energy use of the cooling-water pump. Reducing cooling-water flow increases condensation pressure, decreasing system performance but lowering auxiliary energy consumption. Therefore, the condensation pressure should be set to the minimum value that allows for normal system operation when determining the cooling-water flow rate.

Under steady conditions, the working-fluid flow rate is critical to the distribution of energy and the performance of the ORC system. Higher flow rates increase heat absorption, heat release, and expander output, but also raise pump power consumption and condenser heat load, leading to higher condensation and evaporation pressures. If the flow rate exceeds the optimal value, the additional pump power required outweighs output gains, reducing net shaft power and thermal efficiency. Conversely, a flow rate that is too low limits heat absorption and work capacity, decreasing power generation. Maintaining the working-fluid flow rate within an optimal range ensures balanced net output, cycle efficiency, and operational stability. Operating outside this range diminishes system performance and efficiency.

Expansion pressure, condensation pressure, cooling-water flow rate, and working-fluid flow rate all affect system efficiency and are closely interrelated. Applying control logic to these parameters enables effective parametric analysis of the organic Rankine cycle system, as shown in Figure 2, and provides practical guidance for engineering applications.

Cooling-water temperature varies with environmental conditions. The condenser heat-exchange area limits both the cooling-water flow rate and the condensation pressure, while the expansion pressure and the working-fluid flow rate have optimal values within specific ranges. Therefore, a parametric analysis procedure is proposed to optimize the ORC system, as shown in Figure 2. In this analysis, the cooling-water flow rate and condensation pressure should be coupled. The cooling-water flow rate should be analyzed for internal circulation, while expansion pressure and the working-fluid flow rate should be analyzed for external circulation in sequence. Maximizing yield is the target for determining each parameter's value.

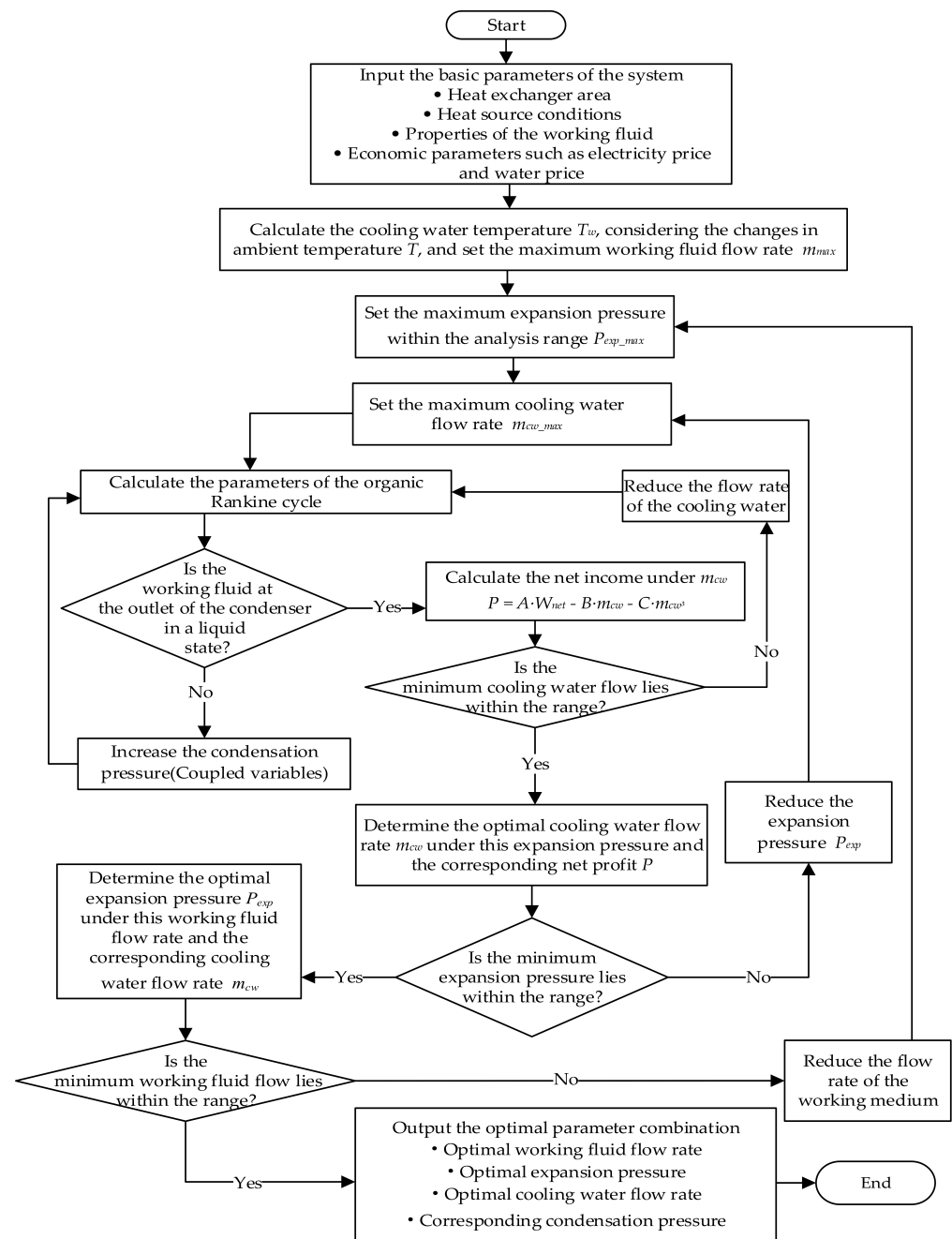


Figure 2. Parametric analysis procedure of ORC system.

4. Simulation and Sensitivity Analysis of an ORC System

This study analyzes an organic Rankine cycle system at an inland factory in Shaanxi Province, China, considering seasonal changes in cooling-water temperature. The system recovers industrial waste heat from the production process, with a flow rate of 20,000 kmol/h, a pressure of 105 Pa, and a temperature decrease from 140 °C to 117 °C, releasing 4407.63 kW of heat. Circulating cooling water serves as the cold source. Both the evaporator and condenser have heat-exchange areas of 200 m². Table 1 summarizes the basic operating conditions.

The thermodynamic model of the ORC system is developed in Aspen Plus. STEAM-NBS is used for the water and steam sides, and REFPROP is used for the organic working fluid (R245fa), as recommended in the ORC modeling literature. Pure R245fa circulates in a closed loop. The heat source is a gas mixture (N₂ = 62%, CO₂ = 12%, H₂O = 18%, and O₂ = 8%) from an industrial process, with the composition based on actual plant data. The

HeatX model in Aspen Plus is used for both the evaporator and condenser. The isentropic efficiencies of the expander and working-fluid pump are set to 0.85. Figure 3 shows the model. For analytical simplicity, the following assumptions are made:

- (1) Pressure drops in heat exchangers and condensers are negligible.
- (2) The system is operated under steady-state conditions.

Table 1. Basic operating condition data parameters.

Parameter	Data
Heat transfer area of evaporator	200 m ²
Heat transfer area of condenser	200 m ²
Expander efficiency	0.85
Pump efficiency	0.85
Work-fluid flow rate	480 kmol/h
Cooling-water flow rate	9000 kmol/h
Cooling-water temperature	22 °C

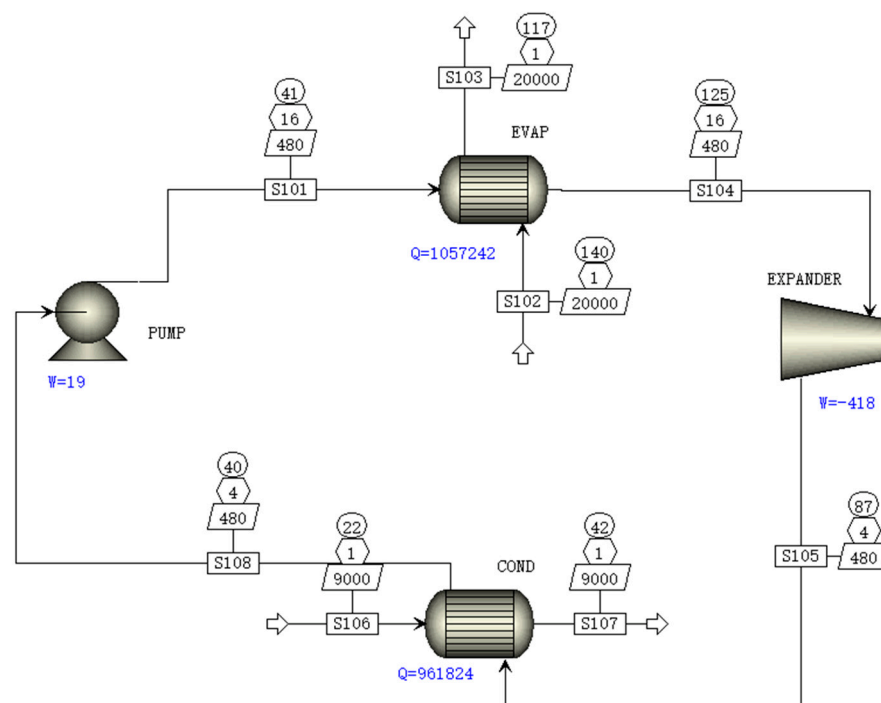


Figure 3. Schematic diagram of the ORC system simulated in Aspen.

4.1. Expansion Pressure

Simulation parameters were chosen to match the factory's actual operating conditions. The selection of simulation parameters is in line with the actual operating conditions of the factory. R245fa was used as the working fluid at a flow rate of 480 kmol/h, chosen for its proven stability and widespread use in engineering applications. Cooling water was supplied at 1.0×10^5 Pa, 22 °C, and 9000 kmol/h. The condensation pressure was set to 3.7×10^5 Pa. A sensitivity analysis was conducted to identify the relationship between net shaft power and expansion pressure, and the results are presented in Figure 4.

Figure 4 shows that net shaft power increases with expansion pressure, peaks at 16.0×10^5 Pa, and then decreases. The system achieves maximum net shaft power at this optimal expansion pressure.

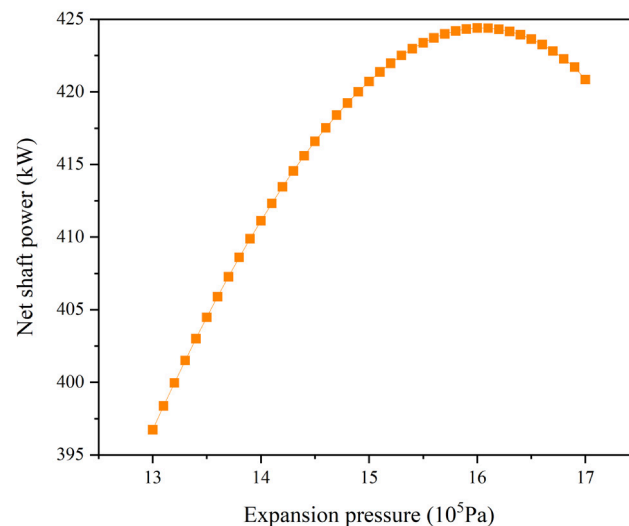


Figure 4. The relationship between net shaft power and expansion pressure at a constant cooling-water flow rate of 9000 kmol/h and a condenser pressure of 3.7×10^5 Pa.

4.2. Condensation Pressure and Cooling-Water Flow Rate

To maximize system output and economic benefit, the lowest feasible cooling-water flow rate should be selected and condensation pressure should be reduced while maintaining normal operation. This approach balances power generation revenue with cooling energy consumption, thereby improving economic efficiency. In the simulation, the working-fluid flow rate was set to 480 kmol/h and the expansion pressure to 16.0×10^5 Pa, based on actual operating conditions and the sensitivity analysis in Section 4.1. The variations in net shaft power and revenue, along with the cooling-water flow rate and condensation pressure, are shown in Table 2, and Figures 5 and 6.

Table 2. Influence of cooling-water flow rate and condensation pressure on net shaft power and revenue.

Cooling-Water Flow Rate (kmol/h)	Condensation Pressure (10^5 Pa)	Net Shaft Power (kW)	Revenue (10^4 CNY/Year)
7000	3.92	407.54	212.00
8000	3.75	420.88	215.81
9000	3.62	431.60	217.45
10,000	3.52	439.84	216.91
11,000	3.44	446.72	214.73
12,000	3.37	452.50	210.95
13,000	3.32	456.93	205.36
14,000	3.28	461.10	198.45
15,000	3.24	464.70	189.96
16,000	3.20	467.84	179.87
17,000	3.17	470.55	168.11
18,000	3.15	472.94	154.64
19,000	3.12	475.07	139.40
20,000	3.11	476.87	122.28
21,000	3.09	478.72	103.38

Figure 5 demonstrates that increasing the cooling-water flow rate enhances the system's net shaft power; however, the associated benefit initially increases and then declines. Figure 6 reveals that as condensation pressure increases, net shaft power decreases, and the benefit also first increases and then decreases. The condensation pressure corresponding to each cooling-water flow rate varies between Figures 5 and 6. At a working-fluid flow

rate of 480 kmol/h and an expansion pressure of 16.0×10^5 Pa, the optimal revenue of 217.45×10^4 CNY/year is achieved with a cooling-water flow rate of 9000 kmol/h and a condensation pressure of 3.62×10^5 Pa. These results indicate the existence of an optimal cooling-water flow rate within the operating range that maximizes system benefits.

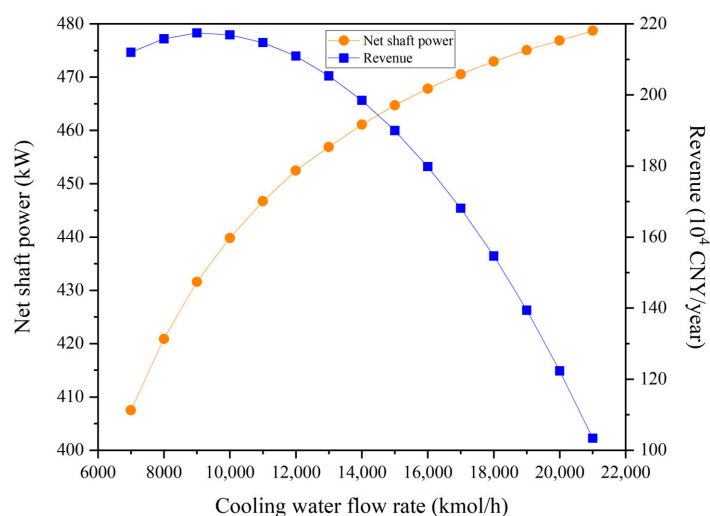


Figure 5. Variations in net shaft power and revenue, along with the cooling-water flow rate, at a constant working-fluid flow rate of 480 kmol/h and an expansion pressure of 16.0×10^5 Pa.

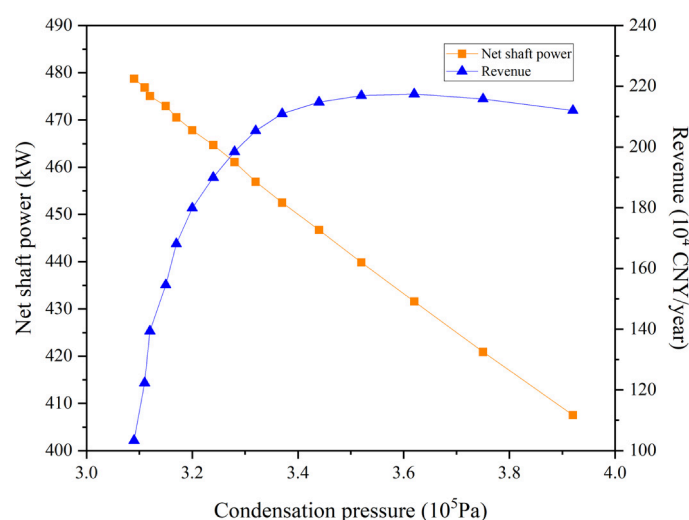


Figure 6. Variations in net shaft power and revenue, along with condensation pressure, at a constant working-fluid flow rate of 480 kmol/h and an expansion pressure of 16.0×10^5 Pa.

4.3. Working-Fluid Flow Rate

The previous analysis shows that changes in the working-fluid flow rate affect the expansion pressure, condensation pressure, and the cooling-water flow rate. A sensitivity analysis was performed to determine how net shaft power, income, and other controllable parameters vary with the working-fluid flow rate. The results are presented in Table 3 and Figure 7.

As the working-fluid flow rate increases from 450 kmol/h to 510 kmol/h, net shaft power and income rise, and then decline. A sudden change occurs when the flow rate increases from 510 kmol/h to 520 kmol/h, due to the cooling-water flow rate increasing from 9000 kmol/h to 10,000 kmol/h. This issue can be prevented by reducing the step size of cooling-water flow rate adjustments. At a working-fluid flow rate of 480 kmol/h, with an expansion pressure of 16.6×10^5 Pa, condensation pressure of 3.59×10^5 Pa, and

cooling-water flow rate of 9000 kmol/h, net shaft power reaches a maximum of 432.81 kW and annual revenue peaks at 218.11×10^4 CNY. Within the operating range, there is an optimal flow rate of the working fluid that maximizes system benefits.

Table 3. Influence of working-fluid flow rate.

Working-Fluid Flow Rate (kmol/h)	Expansion Pressure (10^5 Pa)	Condensation Pressure (10^5 Pa)	Cooling-Water Flow Rate (kmol/h)	Net Shaft Power (kW)	Revenue (10^4 CNY/Year)
450	17.0	3.42	9000	431.64	217.47
460	16.9	3.48	9000	432.16	217.75
470	16.8	3.53	9000	432.79	218.10
480	16.6	3.59	9000	432.81	218.11
490	16.5	3.65	9000	432.51	217.95
500	16.4	3.70	9000	431.95	217.64
510	16.3	3.75	9000	431.63	217.46
520	16.1	3.70	10,000	440.14	217.08
530	16.1	3.74	10,000	439.04	216.47
540	16.1	3.78	10,000	437.95	215.87

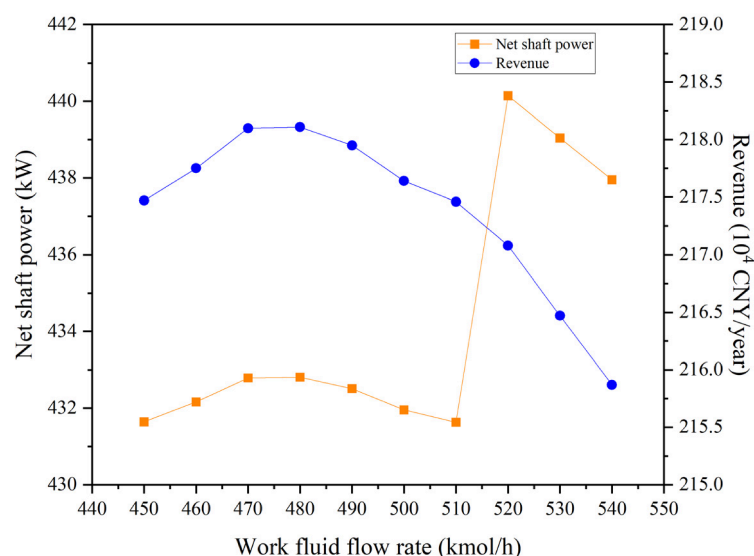


Figure 7. Influence of working-fluid flow rate on net shaft power and revenue.

5. Influence of Seasonal Temperature Changes on ORC System

In organic Rankine cycle (ORC) systems, the heat-source temperature, particularly from industrial waste heat, remains stable, with seasonal fluctuations typically below 5°C . The circulating cooling water, serving as the cold source, is strongly influenced by ambient conditions. While daily temperature changes have minimal impact on the ORC, seasonal fluctuations are the main factor affecting condensation performance and cooling-water costs. Figure 8 presents the average monthly environmental temperature in Xi'an, Shaanxi Province in 2025 as reported by the China Meteorological Administration, along with the actual cooling-water temperature during factory production periods. These data illustrate how ambient temperature affects cooling-water temperature.

The thermodynamic properties of the organic working fluid, such as boiling point, critical temperature, and enthalpy, vary with temperature. Seasonal fluctuations alter these properties, which can impact ORC expansion, energy efficiency, system performance, and operating costs.

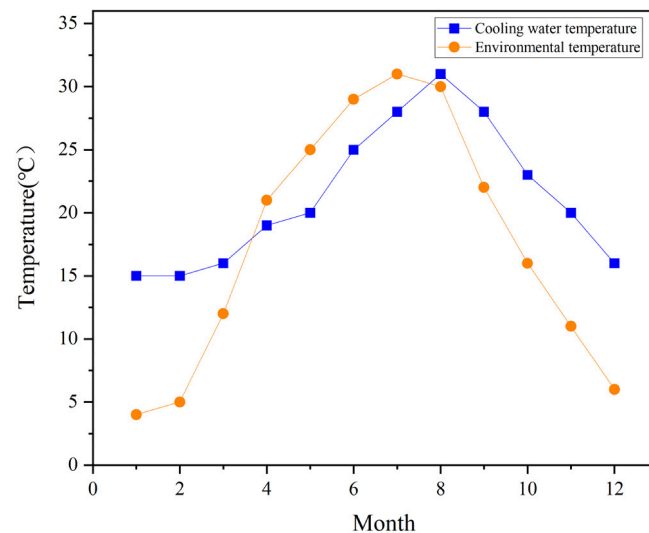


Figure 8. Average temperature trend and cooling-water temperature trend for a factory in Xi'an, Shaanxi province, China, for 2025.

When designing the organic Rankine cycle (ORC) system, equipment size and specifications are typically based on operating conditions that reflect the annual average ambient temperature. For the system using the data in Table 1, the simulation results are provided in Table 4.

Table 4. System simulation results at annual average temperature.

Project	Data
Cooling-water temperature	22 °C
Expander inlet pressure	16.60×10^5 Pa
Pump inlet pressure	3.58×10^5 Pa
Evaporator heat transfer	4113.70 kW
Condenser heat transfer	3630.06 kW
Expander output power	454.31 kW
Pump consumption power	21.50 kW
System efficiency	10.52%
Revenue	218.11×10^4 CNY/year

Seasonal temperature fluctuations require the system to operate under varying conditions for extended periods, with operating parameters showing different cost sensitivities. In April, May, June, October, and November, temperatures are near the annual average, but minor changes during these months cross thresholds between cold and hot seasons. Consequently, the system's operating characteristics deviate slightly from benchmark conditions, requiring targeted adjustments to operating parameters. Detailed parameters are provided in Table 5.

In high-temperature summer conditions, elevated cooling-water temperatures increase condensation pressure, reducing enthalpy gain after evaporation and lowering expander output work. Higher condensation pressure also raises pump power consumption, resulting in a significant decrease in net system output. Additionally, increased cooling-water inlet temperatures reduce the temperature gradient for heat transfer, decreasing condenser efficiency. This leads to higher cooling-water consumption, further increasing efficiency losses and operational costs.

Table 5. System simulation results under near-average temperature.

Parameter	April	May	June	October	November
Working-fluid flow rate (kmol/h)	480	480	480	480	480
Cooling-water flow rate (kmol/h)	9000	9000	9000	9000	9000
Cooling-water temperature	19	20	25	23	20
Expander inlet pressure (10^5 Pa)	16.4	16.4	16.8	16.8	16.4
Pump inlet pressure (10^5 Pa)	3.31	3.40	3.88	3.68	3.40
Evaporator heat transfer (kW)	4208.96	4187.29	4024.19	4063.66	4187.29
Condenser heat transfer (kW)	3709.67	3698.42	3578.04	3602.17	3698.42
Expander output power (kW)	478.32	470.11	430.79	446.48	470.11
Pump consumption power (kW)	21.30	21.20	21.33	21.56	21.20
System efficiency	10.86%	10.72%	10.17%	10.46%	10.72%
Revenue (CNY 10^4)	19.29	18.91	17.11	17.81	18.91

If the system parameters remain unchanged, higher circulating cooling-water temperatures due to seasonal variations can cause cavitation in the working-fluid pump. To maintain normal operation, both condensation temperature and pressure must increase. This requires either a higher cooling-water flow rate or greater cooling tower heat-dissipation capacity to sustain system output. However, these measures significantly increase energy consumption for pumps and cooling tower fans. Evaporation losses and the need for makeup water also rise, further increasing cooling-water treatment and intake costs. To maximize system revenue, parametric analysis is conducted in accordance with the outlined strategy. The results are presented in Table 6.

Table 6. Results of parametric analysis under high-temperature environment.

Parameter	July	August	September
Working-fluid flow rate (kmol/h)	470	460	470
Cooling-water flow rate (kmol/h)	9000	9000	9000
Cooling-water temperature	28	31	28
Expander inlet pressure (10^5 Pa)	17.1	17.4	17.1
Pump inlet pressure (10^5 Pa)	4.13	4.40	4.13
Evaporator heat transfer (kW)	3893.06	3764.16	3893.06
Condenser heat transfer (kW)	3471.10	3364.98	3471.10
Expander output power (kW)	408.00	385.88	408.00
Pump consumption power (kW)	21.10	20.84	21.10
System efficiency	9.94%	9.70%	9.94%
Revenue (CNY 10^4)	16.07	15.07	16.07

Higher ambient temperatures decrease condensation performance and increase cooling-water costs. Adjusting the working fluid circulation rate and evaporation temperature can significantly impact energy efficiency and operational expenses. Increasing the circulation rate may offset some net shaft power loss but also raises pump and cooling-water power consumption, which can cause costs to exceed revenue. Conversely, a controlled increase in evaporation temperature reduces the temperature difference between the working fluid and the cooling water. If net shaft power loss is within acceptable limits, this adjustment lowers cooling-water consumption and improves cost efficiency. Parametric analysis shows that, with a constant cooling-water flow rate, reducing the working-fluid flow rate and increasing the evaporation temperature decreases the system's net shaft power. However, this approach yields optimal revenue during high-temperature summer conditions.

In winter, lower ambient temperatures reduce the inlet cooling-water temperature to 13–18 °C, which significantly improves condensation performance. The evaporator outlet temperature also decreases, resulting in lower expander power output compared to spring or autumn. Lower ambient temperatures reduce the working fluid's condensation pressure, eliminating the need for a high cooling-water flow rate. Consequently, energy consumption for pumps and cooling towers, the volume of cooling-water makeup and treatment costs decline substantially. These conditions support effective parametric analysis and cost control. The results of the parametric analysis are presented in Table 7.

Table 7. Results of parametric analysis under low-temperature environment.

Parameter	December	January	February	March
Working-fluid flow rate (kmol/h)	490	500	500	490
Cooling-water flow rate (kmol/h)	9000	9000	9000	9000
Cooling-water temperature	16	15	15	16
Expander inlet pressure (10^5 Pa)	16.3	15.9	15.9	16.3
Pump inlet pressure (10^5 Pa)	3.10	3.07	3.07	3.10
Evaporator heat transfer (kW)	4310.70	4421.61	4421.61	4310.70
Condenser heat transfer (kW)	3785.83	3886.95	3886.95	3785.83
Expander output power (kW)	503.78	512.04	512.04	503.78
Pump consumption power (kW)	21.82	21.62	21.62	21.82
System efficiency	11.18%	11.09%	11.09%	11.18%
Revenue (CNY 10^4)	20.43	20.82	20.82	20.43

Lower ambient temperatures significantly reduce cooling-water costs. Parametric analysis should focus on maximizing net shaft power and energy efficiency while accounting for auxiliary anti-freezing costs, which are already included in the economic formula. Reducing evaporation temperature and increasing the working-fluid's expansion ratio enhance expander output. The analysis shows that higher flow rates of the circulating cooling water and the working fluid boost both the expander output and the evaporator heat-exchange capacity. While overall system efficiency decreases, system income increases.

Figure 9 shows that evaporation and condensation pressures followed a similar trend throughout the year. Both increased from February to July, peaking in July, and then declined steadily from July to December. The decrease in condensation pressure was more pronounced than that of evaporation pressure, leading to a widening gap between the two curves over time.

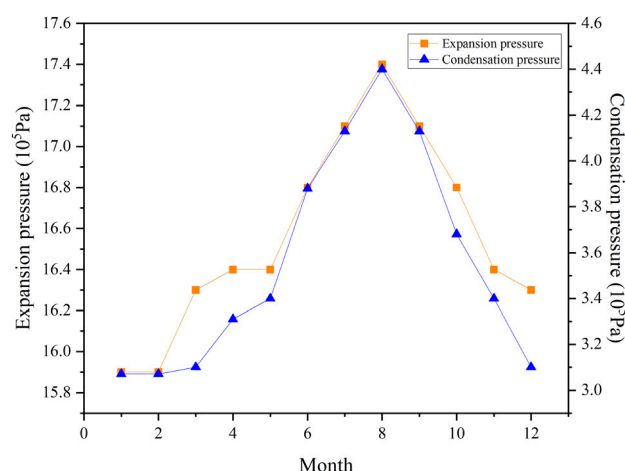


Figure 9. The best expansion pressure and condensing pressure for each month.

Figure 10 shows that the system working-fluid flow rate decreased after peaking in January and February, remained stable from April to June, and reached its lowest point in August. The flow rate then recovered steadily, plateaued slightly from October to November, and increased sharply in December, returning to a higher range.

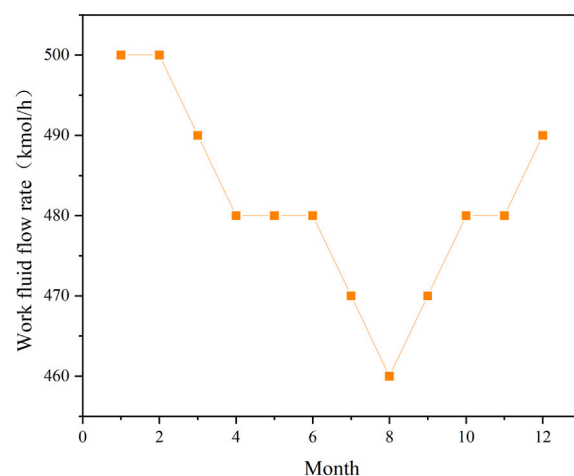


Figure 10. The best working-fluid flow for each month.

Figure 11 shows that both the unit's net shaft power and the project's annual revenue peaked from January to February, declined to their lowest levels in August, and then increased each month. Both saw a significant rise in December, nearing the high values recorded at the start of the year.

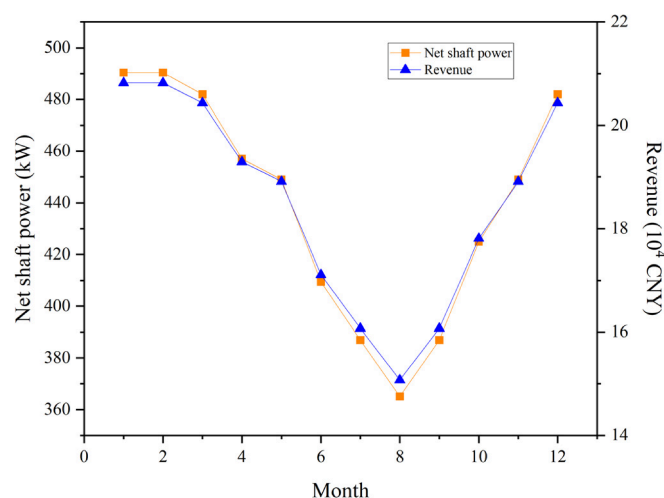


Figure 11. The best net shaft power and revenue for each month.

Figures 12–14 show how key operating parameters affect optimal annual income. Optimal income decreases steadily as cooling-water temperature rises. In contrast, as evaporation pressure, cooling-water flow rate, and working-fluid flow rate increase, optimal income first rises and then falls. This indicates that each parameter has an optimal value within the studied range.

After parametric analysis, the system generates higher monthly revenue than the non-optimized case and reduces the impact of seasonal fluctuations in cooling-water temperature. The system achieves an annual average efficiency of 10.59%, raising total annual income to CNY 2.217 million.

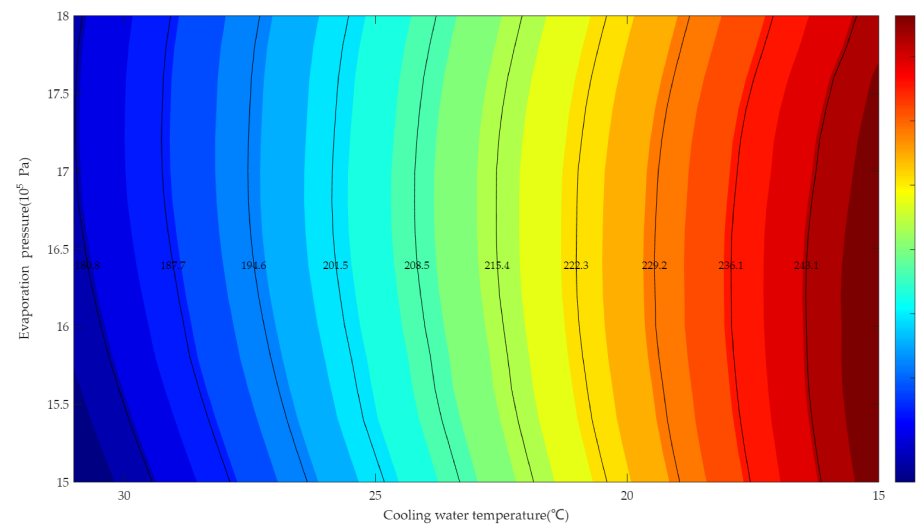


Figure 12. The optimal returns under different cooling-water temperatures and evaporation pressures.

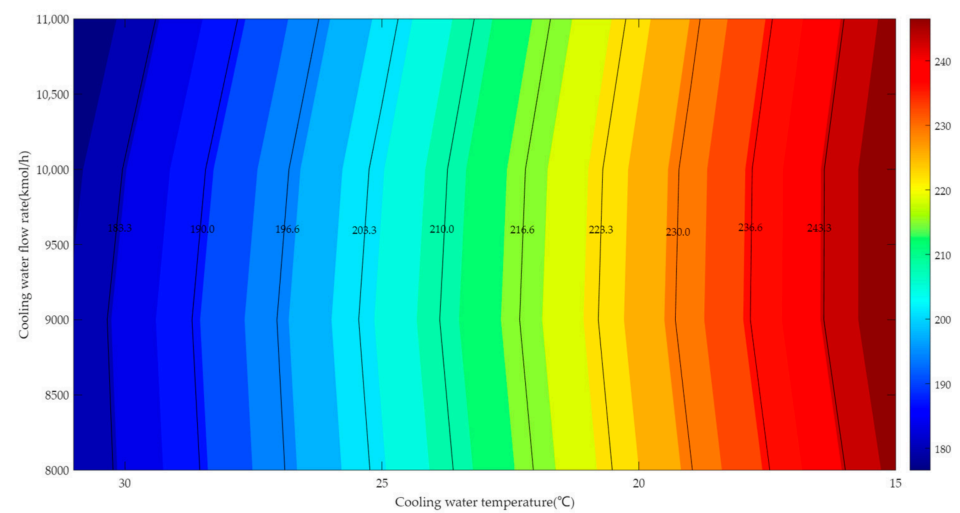


Figure 13. The optimal returns under different cooling-water temperatures and flow rates.

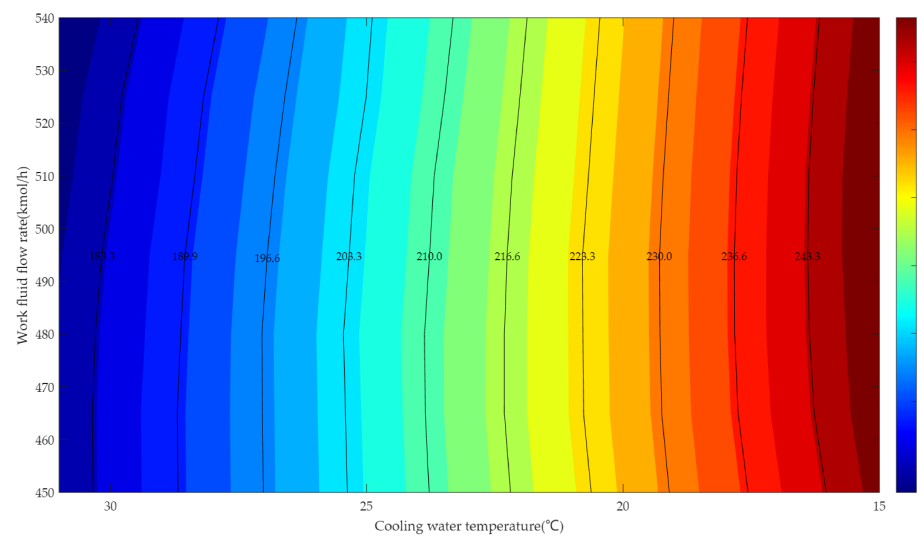


Figure 14. The optimal benefits under different cooling-water temperatures and working-fluid flow rates.

6. Sensitivity Analysis

The sensitivity analyses in this section were conducted at a fixed cooling-water temperature of 22 °C, which reflects the annual average condition at the target site. All other operating parameters were maintained at their nominal values, unless otherwise specified.

6.1. Heat-Source Temperature

A sensitivity analysis was performed to assess the robustness of the optimal results to fluctuations in the heat source. The heat source inlet temperature was varied from 137 °C to 143 °C, with 140 °C as the nominal condition. At each temperature, the parametric screening procedure from Section 4 was repeated to determine the best-performing operating parameters, net shaft power output, and annual profit. Table 8 summarizes the results.

Table 8. Sensitivity analysis of system performance relative to heat-source temperature.

Heat-Source Temperature (°C)	Revenue (10 ⁴ CNY/Year)	Revenue Changes (10 ⁴ CNY/Year)	Net Shaft Power (kW)	Net Shaft Power Changes (kW)	Cooling-Water Flow Rate (kmol/h)	Expansion Pressure (10 ⁵ Pa)	Work Fluid Flow Rate (kmol/h)	Condensation Pressure (10 ⁵ Pa)
137	207.59	−4.82	413.67	−4.42	9000	15.8	465	3.50
138	211.12	−3.20	420.10	−2.94	9000	16.0	480	3.58
139	214.60	−1.61	426.43	−1.47	9000	16.4	480	3.58
140	218.11	0.00	432.81	0.00	9000	16.6	480	3.59
141	221.59	1.60	439.14	1.46	9000	17.0	480	3.59
142	225.05	3.18	445.43	2.92	9000	17.4	480	3.59
143	228.50	4.76	451.70	4.36	9000	17.6	480	3.61

Table 8 shows that as the heat-source temperature increases from 137 °C to 143 °C, annual profit rises from CNY 2.076 million to CNY 2.285 million (10.07%), and net shaft power output increases from 413.67 kW to 451.70 kW (9.19%). The optimal expansion pressure also rises from 15.8 bar to 17.6 bar to maintain the required pinch-point temperature difference. The optimal cooling-water flow rate remains constant at 9000 kmol/h across all temperature levels due to the longer analysis time step. The optimal working-fluid flow rate increases slightly from 465 kmol/h to 480 kmol/h as temperature rises.

The sensitivity analysis indicates an approximately linear relationship between heat-source temperature and both profit and net shaft power output within the studied range. Each 1 °C increase in heat-source temperature results in about a 1.6% increase in profit and a 1.5% increase in net shaft power output. These findings align with sensitivity results reported in the ORC literature for similar temperature ranges. The results demonstrate that while economic performance is sensitive to heat-source temperature, adjusting the operating strategy can maintain near-optimal performance. The recommended parameter selection remains robust across the investigated temperature range.

6.2. Economic Coefficients

To assess the robustness of the economic results given uncertainties in empirical cost correlations, a sensitivity analysis was performed. The net shaft power output revenue coefficient and the cooling-water cost coefficient were each varied by $\pm 10\%$ from their nominal values. The parametric screening procedure was repeated for each combination to evaluate the impact on annual profit and guide optimal parameter selection. The results are summarized in Table 9.

The cooling-water cost coefficient has a relatively small impact on total profit: a $\pm 10\%$ variation in this coefficient changes the total profit by only about $\pm 0.8\%$. In contrast, a $\pm 10\%$ change in the net shaft power output revenue coefficient leads to a profit change of approximately $\pm 11\%$.

Table 9. Sensitivity analysis of system performance relative to net shaft power output revenue and cooling-water cost coefficients.

Net Shaft Power Gain Coefficient	Cooling-Water Cost Coefficient	Revenue (10 ⁴ CNY/Year)	Revenue Changes (10 ⁴ CNY/Year)	Net Shaft Power (kW)	Cooling-Water Flow Rate (kmol/h)	Expansion Pressure (10 ⁵ Pa)	Working-Fluid Flow Rate (kmol/h)
0.55	0.001	218.11	0.00	432.81	9000	16.6	480
0.495	0.0009	195.20	−10.50	432.81	9000	16.6	480
0.495	0.0011	193.40	−11.33	432.81	9000	16.6	480
0.605	0.0009	242.81	11.33	432.81	9000	16.6	480
0.605	0.0011	241.01	10.50	432.81	9000	16.6	480

Across all coefficient combinations, the optimal operating parameters—expansion pressure, cooling-water flow rate, and working-fluid flow rate—remain unchanged. This demonstrates that the recommended system design is robust to uncertainties in the economic coefficients. While absolute profit values vary with cost assumptions, the optimal design point remains stable, supporting the practical applicability of the screening results.

7. Conclusions

During steady-state operation, optimal expansion pressure, condensation pressure, the cooling-water flow rate, and the working-fluid flow rate maximize net shaft power and economic benefit in the ORC system. Deviating from the optimal expansion pressure decreases performance. Higher condensation pressure greatly reduces output, while increasing the cooling-water flow rate lowers condensation pressure but raises operating costs. The working-fluid flow rate must also remain within its optimal range to maintain system performance.

Optimizing ORC system parameters across monthly temperature variations demonstrates that adjusting expansion pressure, condensation pressure, the cooling-water temperature, and the working-fluid flow rates reduces the impact of cooling-water temperature on performance. In low-temperature months, lower cooling-water temperatures improve condensation, enabling a moderate increase in the working-fluid flow rate and a reduction in condensation pressure. This approach increases expander output while minimizing cooling-water costs, resulting in the highest annual revenue. During high-temperature months, higher cooling-water temperatures increase condensation pressure, reduce output, and increase cooling energy consumption, resulting in the lowest annual revenue. During transition months, moderate temperatures allow system parameters to remain stable, maintaining output and revenue without major adjustments. Monthly parametric analysis increases monthly revenue relative to non-optimized conditions, mitigates economic fluctuations due to seasonal temperature changes, and boosts annual revenue by CNY 2.217 million. The system's annual average efficiency reached 10.59%. These results align with reported efficiency ranges for low-temperature ORC systems and confirm the practical viability of the proposed plant-data-driven screening framework under real industrial conditions.

This study uses weather data from a single year (2025). To improve statistical robustness, future work will include multi-year typical meteorological year (TMY) data. Building on current steady-state and seasonal parametric analyses, the equipment, such as expanders and compressors, can be enhanced to improve the model's predictive accuracy across varying weather conditions. Further research will address the transient dynamic characteristics of ORC systems, system response analysis, and adaptive control strategies for diurnal temperature and heat-source load fluctuations. Additionally, integrating exergy economic analysis with life-cycle cost theory will enable the development of a multi-objective parametric analysis model. This approach aims to balance thermodynamic performance, economic benefit, and environmental impact, thereby increasing the comprehensiveness and practical value of the results.

Author Contributions: Y.Y.: Conceptualization, Methodology, Investigation, Software, Visualization, and Writing—original draft. G.L.: Methodology, Writing—review & editing, Supervision, and project administration. L.Z.: Methodology, Writing—review & editing, and Data curation. All authors have read and agreed to the published version of the manuscript.

Funding: Financial support provided by the Key Research and Development Program of Shaanxi Province, China (No. 2025PT-ZCK-09) and the Science and Technology Plan Project of Yuyang District in Yulin, China (No. 2025-GY-04) is gratefully acknowledged.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to third-party restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

Nomenclature and Abbreviations

Nomenclature

$h_{cond,in}$	Enthalpy at the inlet of condenser
$h_{cond,out}$	Enthalpy at the outlet of condenser
$h_{exp,in}$	Enthalpy at the inlet of the expander
$h_{exp,out}$	Enthalpy at the outlet of the expander
$h_{pump,in}$	Enthalpy at the inlet of the pump
$h_{pump,out}$	Enthalpy at the outlet of the pump
m	Working-fluid flow rate
m_{cw}	Cooling-water flow rate
$m_{cw,max}$	Maximum cooling-water flow rate
m_{max}	Maximum working-fluid flow rate
P	Profit/Revenue
P_{exp}	Expander pressure
$P_{exp,max}$	Maximum pressure of the expander
Q_{cond}	Condenser heat rejection
Q_{evap}	Evaporator heat absorption
Q_h	Waste heat energy
T	Environmental temperature
T_w	Cooling-water temperature
$W_{expander}$	Expander output power
W_{net}	Net shaft power
W_{pump}	Pump input power
η_{evap}	Evaporator efficiency
η_{gen}	Generator efficiency
η_{ORC}	Efficiency of the ORC system
η_{pump}	Pump efficiency

Abbreviations

CNY	Chinese Yuan
COND	Condenser
COP	Coefficient of performance
EVAP	Evaporator
GA	Genetic algorithm
HFOs	Hydrogen fluoride olefins
MOGWA	Multi-objective grey wolf algorithm
ORC	Organic Rankine cycle
ORCs	Organic Rankine cycles
VAC	Vapor absorption cycle
VCC	Vapor compression cycle

References

- Ramirez, M.; Epelde, M.; de Arteche, M.G.; Panizza, A.; Hammerschmid, A.; Baresi, M.; Monti, N. Performance evaluation of an ORC unit integrated to a waste heat recovery system in a steel mill. *Energy Procedia* **2017**, *129*, 535–542. [\[CrossRef\]](#)
- Imran, M.; Pili, R.; Usman, M.; Haglind, F. Dynamic modeling and control strategies of organic Rankine cycle systems: Methods and challenges. *Appl. Energy* **2020**, *276*, 115537. [\[CrossRef\]](#)
- Cocco, D.; Serra, F. Performance comparison of two-tank direct and thermocline thermal energy storage systems for 1 MWe class concentrating solar power plants. *Energy* **2015**, *81*, 526–536. [\[CrossRef\]](#)
- Xie, K.; He, H.; Li, Y. A Comparative Study and Experimental Investigation of Multi-Objective Optimization for Geothermal-Driven Organic Rankine Cycle. *Modelling* **2026**, *7*, 44. [\[CrossRef\]](#)
- Li, J.; Yang, Z.; Hu, S.; Duan, Y. Influences of fluid corrosivity and heat exchanger materials on design and thermo-economic performance of organic Rankine cycle systems. *Energy* **2021**, *228*, 120589. [\[CrossRef\]](#)
- Hu, S.; Li, J.; Yang, F.; Yang, Z.; Duan, Y. Multi-objective optimization of organic Rankine cycle using hydrofluorolefins (HFOs) based on different target preferences. *Energy* **2020**, *203*, 117848. [\[CrossRef\]](#)
- González, J.; Llovel, F.; Garrido, J.M.; Quinteros-Lama, H. Selection of a suitable working fluid for a combined organic Rankine cycle coupled with compression refrigeration using molecular approaches. *Fluid Phase Equilibria* **2023**, *572*, 113847. [\[CrossRef\]](#)
- Ndamé Nangué, M.; Nguefack Lekané, N.; Njock, J.P.; Sosso, O.T.; Stouffs, P. Working fluid selection for a high efficiency integrated power/cooling system combining an organic Rankine cycle and vapor compression-absorption cycles. *Energy* **2023**, *277*, 127709. [\[CrossRef\]](#)
- Mahmoud, M.; Alkhedher, M.; Ramadan, M.; Naher, S.; Pullen, K. An investigation on organic Rankine cycle incorporating a ground-cooled condenser: Working fluid selection and regeneration. *Energy* **2022**, *249*, 123742. [\[CrossRef\]](#)
- Gürgen, S.; Altın, İ. Novel decision-making strategy for working fluid selection in Organic Rankine Cycle: A case study for waste heat recovery of a marine diesel engine. *Energy* **2022**, *252*, 124023. [\[CrossRef\]](#)
- Wang, S.; Tang, J.; Liu, C.; Li, Q.; Sun, Z.; Huo, E. Techno-economic-environmental analysis and fluid selection of transcritical organic Rankine cycle with zeotropic mixtures. *J. Clean. Prod.* **2024**, *436*, 140690. [\[CrossRef\]](#)
- Bin Wan Ramli, W.R.; Pesyridis, A.; Gohil, D.; Alshammari, F. Organic Rankine Cycle Waste Heat Recovery for Passenger Hybrid Electric Vehicles. *Energies* **2020**, *13*, 4537. [\[CrossRef\]](#)
- Ding, Z.; Wu, S.; Ji, C.; Feng, X.; Shi, Y.; Liu, B.; Chen, W.; Bai, Q.; Zhou, H.; Huang, H.; et al. Optimal Working Fluid Selection and Performance Enhancement of ORC Systems for Diesel Engine Waste Heat Recovery. *Energy Eng.* **2026**, *123*, 27. [\[CrossRef\]](#)
- Hu, B.; Guo, J.; Yang, Y.; Shao, Y. Selection of working fluid for organic Rankine cycle used in low temperature geothermal power plant. *Energy Rep.* **2022**, *8*, 179–186. [\[CrossRef\]](#)
- Xu, W.; Zhao, L.; Mao, S.S.; Deng, S. Towards novel low temperature thermodynamic cycle: A critical review originated from organic Rankine cycle. *Appl. Energy* **2020**, *270*, 115186. [\[CrossRef\]](#)
- Yang, F.; Yang, F.; Liu, Q.; Chu, Q.; Yang, Z.; Duan, Y. Thermodynamic analysis of working fluids: What is the highest performance of the sub- and trans-critical organic Rankine cycles? *Energy* **2022**, *241*, 122512. [\[CrossRef\]](#)
- Imre, A.R.; Ahmed, A.M. Effect of the working fluids critical temperature on thermal performance for trilateral flash cycle and organic Rankine cycle. *Int. J. Thermofluids* **2023**, *20*, 100417. [\[CrossRef\]](#)
- Li, Y.; Wu, D.; Wetenhall, B. Pressure drop study on an Organic Rankine System utilizing LNG cryogenic energy and waste heat recovery. *Energy Procedia* **2019**, *158*, 718–725. [\[CrossRef\]](#)
- He, T.; Lv, H.; Shao, Z.; Zhang, J.; Xing, X.; Ma, H. Cascade utilization of LNG cold energy by integrating cryogenic energy storage, organic Rankine cycle and direct cooling. *Appl. Energy* **2020**, *277*, 115570. [\[CrossRef\]](#)
- Wang, S.; Liu, C.; Li, Q.; Liu, L.; Huo, E.; Zhang, C. Selection principle of working fluid for organic Rankine cycle based on environmental benefits and economic performance. *Appl. Therm. Eng.* **2020**, *178*, 115598. [\[CrossRef\]](#)
- Zhu, H.; Zhang, X.; Gao, Z.; Wang, L.; Wang, Z. Thermodynamic analysis and experimental study of two-stage thermal-gravitational pumping ORC under low evaporation temperatures. *Sustain. Energy Technol. Assess.* **2024**, *66*, 103820. [\[CrossRef\]](#)
- Işık, M.; Bilir Sağ, N. A novel Geothermal-Powered combined ORC–Dual evaporator refrigeration system for Power, Cooling, and Heating: Exergetic, exergoeconomic and exergoenvironmental (3E) analysis. *Eng. Sci. Technol. Int. J.* **2026**, *76*, 102323. [\[CrossRef\]](#)
- Chen, C.; Mu, H.; Wang, H.; Li, N.; Zhao, X.; Liu, Q. Performance enhancement of LNG cold-energy-generation ORC system with liquid-separation evaporator: Thermal economic analysis of dual-stage condensation ORC. *Appl. Therm. Eng.* **2025**, *265*, 125554. [\[CrossRef\]](#)
- Li, P.; Yin, H.; Yang, Y.; Zhou, C.; Wang, Z.; Han, Z. Three-configuration performance assessment and optimization of Carnot batteries with low-temperature thermal integration coupled to organic Rankine cycles. *J. Energy Storage* **2026**, *153*, 120825. [\[CrossRef\]](#)
- Park, J.H.; Kim, J.; Kwon, J.G. 50 kWe R1336mzz(Z) ORC power generation system for industrial waste heat recovery: System design and commissioning test results. *Energy* **2025**, *323*, 135698. [\[CrossRef\]](#)

26. Wang, C.; Wang, X.; Wang, H.; Xu, Y.; Wen, M.; Wang, Y.; Tan, J.; Hao, L.; Ge, Y. Multi-objective optimization of a diesel engine-ORC combined system integrating artificial neural network with genetic algorithm. *Fuel* **2024**, *371*, 131981. [[CrossRef](#)]
27. Gu, Z.; Feng, K.; Ge, L.; Quan, L. Dynamic modeling and optimization of organic Rankine cycle in the waste heat recovery of the hydraulic system. *Energy* **2023**, *263*, 125673. [[CrossRef](#)]
28. Zhang, Q.; Feng, Y.-Q.; Xu, K.-J.; Liang, H.-J.; Liu, Z.-N.; Zhao, C.-Y.; Wang, Y.-Z.; Sapin, P.; Markides, C.N. Dynamic behaviour and performance evaluation of a biomass-fired organic Rankine cycle combined heat and power (ORC-CHP) system under different control strategies. *Appl. Therm. Eng.* **2024**, *248*, 123236. [[CrossRef](#)]
29. Peng, C.; Xu, J.; Yang, H.; Yan, L.; Wang, S. Geothermal-driven polygeneration plant integrating air separation, LNG cooling, ORC, and PEME: Thermo-Enviro-Economic analysis and ML-based optimization. *Renew. Energy* **2026**, *269*, 125839. [[CrossRef](#)]
30. Zhao, L.; Liu, G. A comprehensive framework for targeting the disturbance propagation path and debottleneck strategy of chemical process considering the topology and cascading effects. *Energy* **2024**, *301*, 131772. [[CrossRef](#)]
31. Zhao, L.; Liu, G. Optimization of catalyst service cycle and start-up considering the reactor-distillation-HEN integration and climate. *Chem. Eng. Sci.* **2024**, *299*, 120517. [[CrossRef](#)]
32. She, Y.; Jiang, G.; Song, Z.; Zhao, L.; Liu, G. Performance evaluation and optimization strategies of cooling water system considering ambient temperature. *Appl. Therm. Eng.* **2025**, *279*, 127785. [[CrossRef](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.