energies

Review

Design and Optimization of Organic Rankine Cycle Based on Heat Transfer Enhancement and Novel Heat Exchanger: A Review

Pei Lu †, Zheng Liang †, Xianglong Luo *, Yangkai Xia, Jin Wang, Kaihuang Chen, Yingzong Liang, Jianyong Chen, Zhi Yang, Jiacheng He and Ying Chen

Guangdong Provincial Key Laboratory of Functional Soft Condensed Matter, School of Material and Energy, Guangdong University of Technology, No. 100 Waihuan Xi Road, Guangzhou Higher Education Mega Center, Panyu District, Guangzhou 510006, China
* Correspondence: lxl-dte@gdut.edu.cn
† These authors contributed equally to this work.

Abstract: The effective exploitation of renewable energy and the recovery of waste heat are two crucial strategies in achieving carbon neutrality. As an efficient and reliable heat-to-power conversion technology, the organic Rankine cycle (ORC) has been recognized and accepted by academia and industry for use in solar energy, geothermal energy, biomass energy, and waste heat applications. However, there remain unsolved technical challenges related to the design and operation of the components and system. As the exergy destruction and investment cost of heat exchangers exert significant influence on the performance of ORC, investigations on the performance improvement of heat exchangers are of great significance. The aim of this paper was to provide a review on the performance improvement of ORC in relation to heat transfer enhancement, heat exchanger design optimization, and cycle construction based on a novel heat exchanger. The performance of ORC using different types of heat exchangers was discussed and the importance of revealing the influence of heat exchanger structural parameters on ORC performance was assessed. The heat transfer enhancement, novel heat exchanger investigation, and the ORC configuration development based on a novel heat exchanger were emphasized. Finally, developments and current challenges were summarized and future research trends were also identified.

Keywords: organic Rankine cycle; heat transfer enhancement; heat exchanger; optimization

check for updates

Citation: Lu, P.; Liang, Z.; Luo, X.; Xia, Y.; Wang, J.; Chen, K.; Liang, Y.; Chen, J.; Yang, Z.; He, J.; et al. Design and Optimization of Organic Rankine Cycle Based on Heat Transfer Enhancement and Novel Heat Exchanger: A Review. *Energies* **2023**, *16*, 1380. https://doi.org/10.3390/en16031380

Academic Editors: Yuanyuan Duan and Jian Li

Received: 30 November 2022
Revised: 7 January 2023
Accepted: 10 January 2023
Published: 30 January 2023

1. Introduction

The energy crisis and climate change caused by reliance on fossil fuels have emerged as major threats in recent years [1]. To strike a balance between growing energy demand and global environmental protection, corresponding carbon neutral targets have been proposed worldwide [2]. The development and utilization of renewable energy and recovery of waste heat are two effective measures to achieve the goal of carbon neutrality [3]. As a reliable and efficient heat-to-power conversion technology, the organic Rankine cycle (ORC) has gained recognition and acceptance in academia and industry for the utilization of waste heat [4] and renewable energy (e.g., solar energy [5], ocean energy [6], geothermal energy [7], and biomass energy [8]). As a result, promoting the application of ORC systems is one of the primary techniques of achieving carbon neutrality.

ORC technology is a well-grounded and promising way to convert heat to power due to its simple structure, moderate operating parameters, flexible operation, and excellent thermo-economic performance [9]. Figure 1 displays the schematic of a traditional ORC system, consisting of an evaporator, a condenser, a pump, and an expander. As shown in Figure 1, the technical principle of ORC is consistent with that of the traditional Rankine cycle. First, the working fluid becomes high-pressure vapor by absorbing heat energy from the heat source (waste heat or renewable energy) in the evaporator. Then, the low-pressure exhaust flows into the condenser to release heat to the heat sink after driving the expander to generate electricity. Finally, the liquid fluid is discharged from the condenser into the working fluid pump to be pressurized. The first ORC prototype can be traced back to 1826, when Howard [10] experimentally investigated a power cycle using ether and established the principle of ORC technology. The ORC has experienced a much more robust development due to economic incentives and surging energy prices since the 1970s [10]. Some reviews [11–13] focused on the development of the architectures, markets, technologies, and applications of the ORC system. In the ORC system, heat exchangers are vital components that absorb heat from the heat source or release heat to the heat sink [14]. Literature studies have proven that the exergy destruction of heat exchangers accounts for 70–90% of the total exergy destruction of the ORC [15,16]. Moreover, the investment cost of the heat exchanger even takes up 80% of the ORC total investment [17]. Thus, enhancing the comprehensive performance of heat exchangers is currently a research hotspot to improve the ORC's efficiency in converting waste heat or renewable energy into electricity.

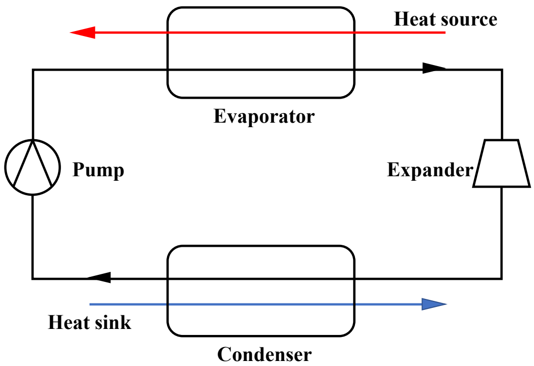


Figure 1. Schematic of a simple ORC system.

The heat exchanger is a device for heat transfer from a high temperature medium to a low temperature medium and is widely applied in refrigeration, heating, combustion engines, power plants, petrochemical plants, chemical plants, and natural gas refining [18]. The design and performance improvement of heat exchangers require multiple disciplines, including thermodynamics [19], transport phenomena [20], fluid mechanics [21], and materials [22]. There are various kinds of heat exchangers, e.g., plate, double pipe, shell-and-tube, fin-and-plat, fin-and-tube, gasket, and spiral tube heat exchanger [23]. An ORC system contains at least one evaporator that absorbs energy from the heat source and one condenser that releases exhaust heat. The number of heat exchangers is determined according to the ORC configuration [24]. It is worth noting that the temperature difference between the condensation and evaporation temperatures is relatively small in the ORC. Thus, the heat transfer enhancement of the heat exchanger has a remarkable influence on the ORC's thermo-economic performance [25]. As the exergy destruction and investment cost of heat exchangers exert a major influence on the performance of the ORC, the heat transfer enhancement of heat exchangers has been a long-term and hot topic in the research community of the ORC, and has received increasing attention from the academia and industry. Scholars have studied ORC heat exchangers in the field of design optimization, heat transfer enhancement, experimental testing, performance comparison, configuration improvement, fluid screening, and novel heat exchanger applications. However, the results of this related research are scattered and independent.

Despite the fact that there have been a number of screening or performance enhancement reviews on mechanical components in ORC systems [26,27], publication reviews on the research status of heat transfer enhancement in ORC are still lacking, which seriously impedes the systematic cognition of scholars and the development of heat transfer enhancement in ORC.

The contribution of this study was to provide a review on the performance improvement of ORC related to theat transfer enhancement, heat exchanger design optimization, and cycle construction based on an enhanced heat transfer process or novel heat exchanger. The performance of ORC using various types of heat exchangers was discussed and the importance of revealing the influence of heat exchanger structural parameters on ORC performance was assessed. Heat transfer enhancement, novel heat exchanger investigation, and the ORC's configuration development based on a novel heat exchanger were highlighted. The conclusion summarized developments and current challenges, and also identified future research trends.

2. Heat Exchangers Used in the ORC

Typical heat exchangers, such as fin-and-tube, plate, and shell-and-tube heat exchangers, are mostly applied in ORC systems on account of their high performance, low cost, and easy maintenance [28]. To reveal the connection between different types of heat exchangers and ORC system, a comparison of ORC with different heat exchangers is necessary. Thus, this section first presents a brief introduction of typical heat exchangers. Then, a comparison and systematic review of conventional types of heat exchangers in ORC systems were presented.

2.1. Heat Exchanger Type

In Section 2.1, the three types of heat exchangers (plate, shell-and-tube, and fin-and-tube heat exchangers) which are mostly applied in ORC systems are introduced from the perspectives of their structures and characteristics.

2.1.1. Plate Heat Exchanger

A plate heat exchanger is made of corrugated metal sheets that are stacked on top of each other and can be fixed in frames or welded [29]. Each group of plates is stacked by two single plates with the same direction of corrugation, which is gripped and assembled in the frame by clamping plate. The four edges of two adjacent plates groups are sealed with special rubber gaskets. The plates and gaskets form the channel of thermal fluid after being superimposed and assembled. High-temperature and low-temperature mediums flow in channels on either side of each plate for heat transfer. There are three typical plate forms: herringbone corrugated plate, horizontal straight corrugated plate, and beaded plate. Figure 2 shows the structural schematic of herringbone plate. Compactness, convenient dismounting, and high heat transfer efficiency are the main features of the plate heat exchanger.

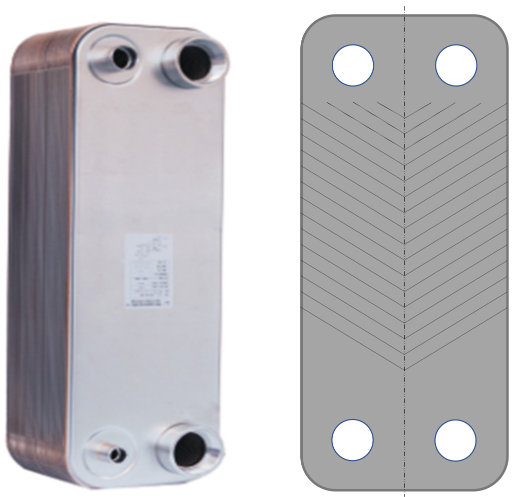


Figure 2. Structural schematic of a herringbone plate heat exchanger [30]. Reproduced with permission from Luo et al., Energy; published by Elsevier, 2022.

2.1.2. Shell-and-Tube Heat Exchanger

A shell-and-tube heat exchanger is composed of a bundle of tubes and a cylindrical shell [31]. Figure 3 depicts the structural schematic of a shell-and-tube heat exchanger. One fluid flows inside the bundles of tubes while the other fluid flows through the pressure vessel shell. Straight tubes and U-tubes are common tube geometries of shell-and-tube heat exchangers, while the arrangement of the tube bundle is generally in the form of a triangle or square. The triangular arrangement yields the advantages of steady configuration and a greater volume of tube installation to enhance the heat transfer area, and features high flow resistance and pressure drop. The square pattern is simplified for easy maintenance and cleaning by sacrificing a portion of the heat transfer area [32]. There are baffle plates on the shell side which direct the fluid to effectively flush the tubes. Furthermore, the baffle plates play a part in supporting the tube bundle.

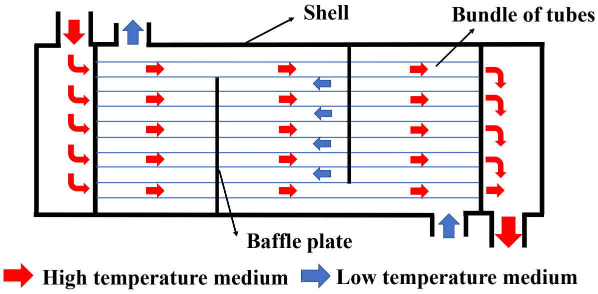


Figure 3. Structural schematic of shell-and-tube heat exchanger [33]. Reproduced with permission from Li et al., Energy Conversion and Management; published by Elsevier, 2019.

2.1.3. Fin-and-Tube Heat Exchanger

Figure 4 shows the structural schematic of a fin-and-tube heat exchanger. The main components of a fin-and-tube heat exchanger are tubes, fins, and baffles. The tube side of a fin-and-tube heat exchanger is divided into several tube passes consisted of short tube banks and a pair of headers at both ends. The tube can be divided into a circular tube, elliptical tube, and flat tube based on its shape. The surface structure of the fins with longitudinal or radial forms includes flat wing, broken wing, corrugated wing, and perforated wing, etc. In addition, the fin can be arranged outside the tube and/or inside the tube. The high- and low-temperature medium transfers heat through the tube wall and fins. The fin-and-tube heat exchanger is one of the earliest and most successful discoveries in heat transfer enhancement [34]. This method is still the most widely used of all the surface heat transfer enhancements for different types of heat exchangers [35].

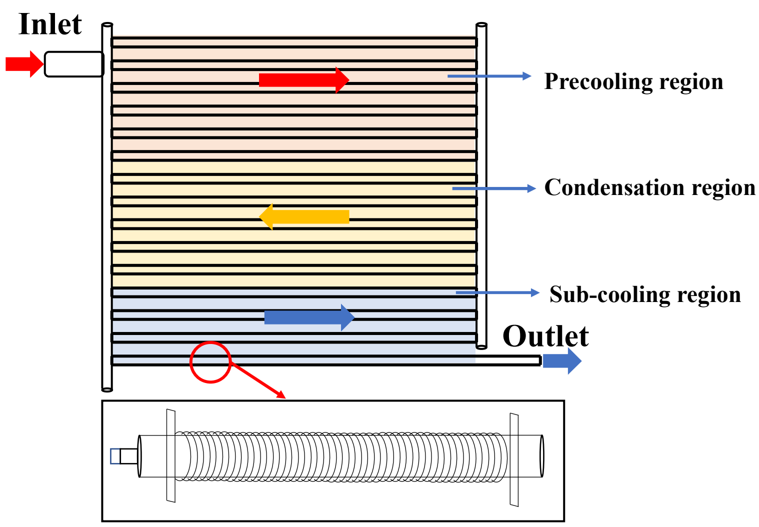


Figure 4. Structural schematic of fin-and-tube heat exchanger.

This sub-section elaborates on the commonly used heat exchangers in the ORC system. The purpose of this study was to summarize various heat transfer enhancement technologies in the ORC system. The involved heat transfer enhanced approaches or novel heat exchangers are almost all based on the three types of conventional heat exchangers listed above. To demonstrate whether an improvement is effective, it is generally essential to compare the thermo-economic performance of novel technologies with that of traditional technologies.

2.2. Comparison and/or Screening of Heat Exchangers in the ORC

The selection of an appropriate type of heat exchanger is basically dependent on the configurations of the ORC system, the working fluid, the working conditions, and especially the evaluation criterion. As mentioned above, the life-span performances of the ORC system, such as the thermal efficiencies, heat transfer efficiency, investment cost, and payback period, are significantly affected by the performance of the heat exchanger. However, each type of heat exchanger favors different working conditions due to the different structures and heat loads, leading to variations in the operating performance of the ORC. Consequently, the specific selection and comparison of the heat exchanger are necessarily conducted according to the specific working conditions.

2.2.1. Comparison of ORC Using Different Types of Heat Exchangers

As mentioned above, heat exchangers obviously play an important role in ORC system due to the high proportion of investment cost and exergy destruction. It is necessary to conduct a comparison and/or screening of ORC systems using different types of heat exchangers to verify the superiority of certain types of heat exchangers under specific conditions.

Walraven et al. [36] integrated shell-and-tube heat exchangers and plate heat exchangers into ORCs with different working fluids and undertook a performance comparison between the two categories of heat exchangers in ORCs. Consideration was given to the impact of the system boundary conditions and heat exchanger structure parameters on the operating performance of ORC. The results showed that the heat-transfer coefficients of the plate heat exchangers outperformed those of shell-and-tube heat exchangers, resulting in a smaller pinch-point temperature difference and system power output. Lee et al. [37] studied the system response of a 50 kW ORC using a plate evaporator or shell-and-tube evaporator. The results showed that the superheat depends on the type of evaporator used. The system operation may be unstable when the superheat in the plate evaporator is less than 10 °C. However, there is a large enough space above the tube bundle to mitigate the shear effect of the vapor in a shell-and-tube evaporator. Bull et al. [38] conducted a comparison between the shell-and-tube heat exchanger and the plate heat exchanger. The results showed that the plate heat exchanger has a lower area requirement of slightly over 25% at the evaporator and almost 40% at the condenser. Similar results can be obtained in the study by Xu et al. [39]. It is worth noting that these works only focused on component performance. Xu et al. [39] pointed out that the ORC system level and the heat exchanger level should be taken into account simultaneously to reduce the influence of improper parameter assumptions on system technique parameters and economic indicators.

At the system level, Zhang et al. [28] pointed out that there are significant differences and complexities in thermo-economic comparisons of different ORC system. Consequently, they built a thermo-economic model to present a comparison of four ORC configurations with different combinations of heat exchangers. The shell-and-tube heat exchanger, plate heat exchanger, and fin-and-tube heat exchanger were considered as condensers or evaporators in these four ORC configurations: both condenser and evaporator using a plate heat exchanger (ORC-PP); a plate heat exchanger as a condenser and a fin tube bundle with circular fins as evaporator (ORC-FP)-; both the condenser and evaporator using shell-and-tube heat exchangers (ORC-SS); and a shell-and-tube heat exchanger as condenser and a fin tube bundle with circular fins as an evaporator (ORC-FS). The results revealed that the electricity production costs of ORC-PP and ORC-SS are 54.54–114.28% higher than that of

ORC-FP and ORC-FS. The gap of various ORC configurations narrows gradually with the increment of the evaporation pressure. Among them, ORC-FS is the most cost-effective ORC configuration, with a payback period of 4.3–5.6 years.

The above-mentioned research on heat exchangers was based on specific operating conditions to compare the design performance of the heat exchangers. However, the steady-state condition is impractical for the ORC operation due to the volatility of the heat source/sink. Therefore, the off-design operating performance of heat exchanger is worthy to be investigated. Manuel et al. [40] compared the dynamic response of indirect evaporation in the shell-and-tube evaporator and direct evaporation in the fin-and-tube evaporator under fluctuations of an internal combustion engine exhaust in accordance with relevant frequencies and amplitudes of a standard driving cycle. They found the most suitable range of frequencies and amplitudes of heat source fluctuations for direct evaporation. A case study of exhaust waste heat recovery from a diesel engine was conducted to verify the superiority of a direct evaporator over an indirect evaporator in their explored work [41]. The expander can be protected from damage of liquid droplets with an amplitude below approximately 20 kW using a direct evaporation in the fin-and-tube evaporator. The direct evaporator has an 88% lower weight and a 70% smaller volume than the indirect evaporator. Chatzopoulou et al. [42,43] also evaluated the off-design performance of an ORC using a plate heat exchanger or double pipe heat exchanger in the heat recovery from a stationary internal combustion engine (ICE). The results showed that the design area requirement of plate heat exchanger was 50% lower than that of double pipe heat exchanger due to the relatively higher equivalent heat transfer rate, reducing the investment cost. Under off-design conditions in which the ICE load was dropped from 100% to 60%, the heat transfer rate reduced remarkably, by up to 30% in the double pipe heat exchanger and 25% in plate heat exchanger, respectively. The net power output (W_{net}) of the ICE-ORC using the plate heat exchanger was approximately 4–10% higher than that using the double pipe heat exchanger.

These previous studies compared the thermodynamic and economic performance of different heat exchangers under system designs, dynamic responses, thermo-economic performance, and off-design operations, respectively. Among them, the plate heat exchanger showed a strong heat transfer performance, leading to a compact structure. However, the operating conditions of the plate heat exchanger are much stricter. The deficiency of plate heat exchangers is that the geometry of both sides of the heat exchanger is identical, bringing about an inefficient heat exchanger when the two fluid streams need completely different channel geometries [36]. In addition, the economic performance of the heat exchanger, which is related to heat transfer performance, heat transfer area, operating pressure, should be taken into account alongside the ORC system operating performance during the design process. The ORC configuration, which employs a fin-and-tube heat exchanger as the evaporator and a shell-and-tube heat exchanger as the condenser, demonstrates outstanding thermo-economic performance. Direct evaporation is a great method to absorb waste heat when designing an ORC, but operating safety should be considered. Overall, the economic performance of the ORC system, the dynamic responses, and the off-design performance of the heat exchanger need to be simultaneously considered during the design process.

2.2.2. Comparison of ORC Using Heat Exchangers with Different Structural Parameters

The geometrical parameters of the heat exchanger are a key factor in evaluating the performance of system. In theory, the larger the size of the heat exchanger, the better the operation performance. For an air-cooled-ORC, the investment cost of the heat exchanger takes up approximately 80% [17]. Simply increasing the size of the heat exchanger does not improve the economic performance of the ORC. The comparison between different structural parameters of the same type of heat exchanger warrants correspondingly further research.

Some scholars investigated the influences of various heat exchanger arrangements and forms of the components on ORC performance. Rohmah et al. [44] evaluated the influence of different plate spacing on the total heat transfer area and total pressure drop. In the plate condenser, the channel velocity and Reynold number decrease with the increment in the plate spacing due to the increase of the equivalent diameter-, and channel cross-sectional area, resulting in an increment in the total heat transfer area and a decrease in pressure drop. Ravi et al. [45] tested the effects of changing the fin geometries of the internally–externally protruded and fin counter flow heat exchanger on heat recovery performance. The results indicated that the brake thermal efficiency was enhanced by 32–37% by increasing the number and length of the fins. However, the economic performance of the ORC system was not considered in Rohmah et al. [44] or Ravi et al. [45]. Luo et al. [46] studied the effects of different tube configurations of a liquid–vapor separated condenser on the thermo-economic performance of the ORC system. They stated that the investment cost varied sharply and monotonously with the tube length, tube inner diameter and tube pass configuration, whereas the thermal efficiency of the ORC changed slightly with the tube pass configuration. Li et al. [33] analyzed the effects of the flow direction of the heat source/sink medium and working fluid in a shell-and-tube heat exchanger on the thermo-economic performance of the ORC system. The results demonstrated that the optimal heat exchanger arrangement is dependent on the heat source temperature and working fluid, and that the ORC investment costs for different heat exchanger arrangements can vary by as much as 14.7%.

Some scholars evaluated the impacts of heat exchanger size on the performance of components and/or ORC. Chen et al. [16] constructed an ORC test bench with different evaporators (heat transfer area of 3.30, 6.56, and 3.71 m^2) and condensers (heat transfer area of 10.00, 13.59, and 1.62 m^2), as shown in Figure 5. Advanced exergy analysis on the ORC was conducted. However, the comparisons between heat exchangers of different sizes were not reported. In addition, Zhang et al. [47] experimentally studied the ORC systems with rated power capacities of 3 kW and 10 kW. Different sizes of plate evaporator were applied in the 3 kW (area of heat transfer: 4.175 m^2) and 10 kW (area of heat transfer: 16.18 m^2) ORC systems. The results showed that based on the same environmental conditions and the similar system structure, the ORC system with a larger capacity operates better with sufficient heat source input. However, the behaviors of the heat exchanger were also not reported. Since the reported experiment test rigs vary from and the ORC test rig lacks a benchmark, it is hard to compare the experimental results in the literature. Thus, based on the ORC test bench by Chen et al. [16], Zheng et al. [48] compared the ORC performance ORC with six combinations of plate heat exchangers. They defined an equivalent overall heat transfer coefficient and a heat exchanger area utilization indicator to compare the operating behavior of different sizes of plate heat exchangers. The heat transfer temperature differences of heat exchangers tend to decrease with the rise in heat transfer areas, leading to a increase in W_{net} and thermal efficiency. Figure 6 demonstrates the operation behavior of different heat exchanger combinations in Zheng et al. [48]. As shown in Figure 6a,b (E and C represent the evaporator and condenser, respectively), the overall heat transfer coefficient of evaporator (U_{eva}) decreases significantly when the area increases from 3.71 m^2 to 6.56 m^2. The downward trend of the overall heat transfer coefficient of condenser (U_{con}) is similar to that of the evaporator. It is worth noting that the U_{con} is considerably affected by the evaporator area because the condenser inlet density of the working fluid drops with the increment in the heat load of the evaporator. As shown in Figure 6c, the heat exchanger area utilization indicators decrease with the increment in the heat exchanger area because the increment rate in W_{net} is lower than that in the heat exchanger area, which states that the heat transfer areas are ineffectively utilized.

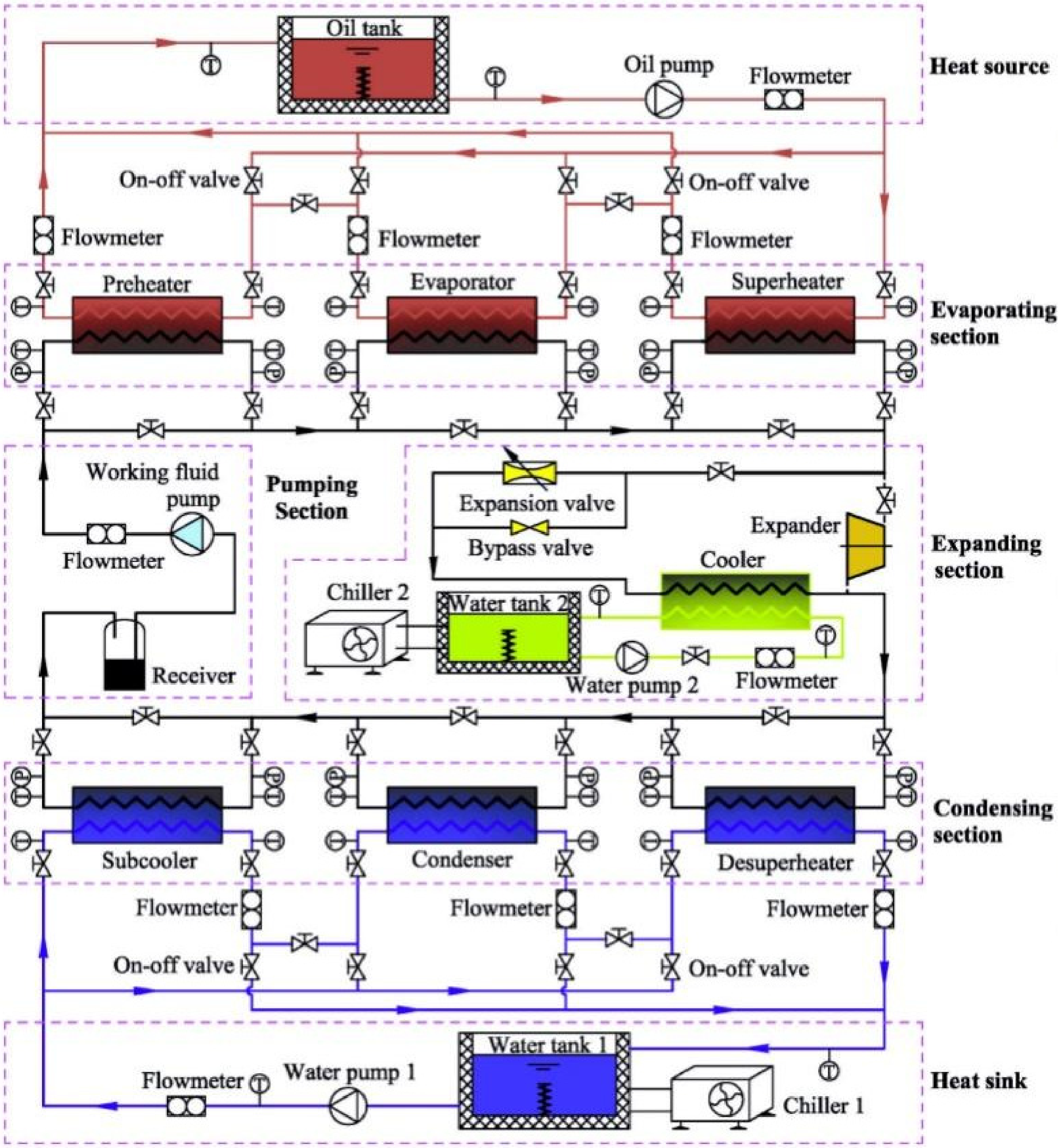


Figure 5. Schematic of the test rig of the ORC system [16]. Reproduced with permission from Chen et al., Energy Conversion and Management; published by Elsevier, 2019.

These previous experimental studies compared the thermodynamic performance of the different structural parameters of the same type of heat exchanger, demonstrating that the heat transfer areas and combinations remarkably influence the operation behavior of these heat exchangers and ORC systems. However, comparison studies of heat exchangers of different sizes are scarce, and many other types of heat exchangers have not been reported. It is an emerging topic that deserves further study.

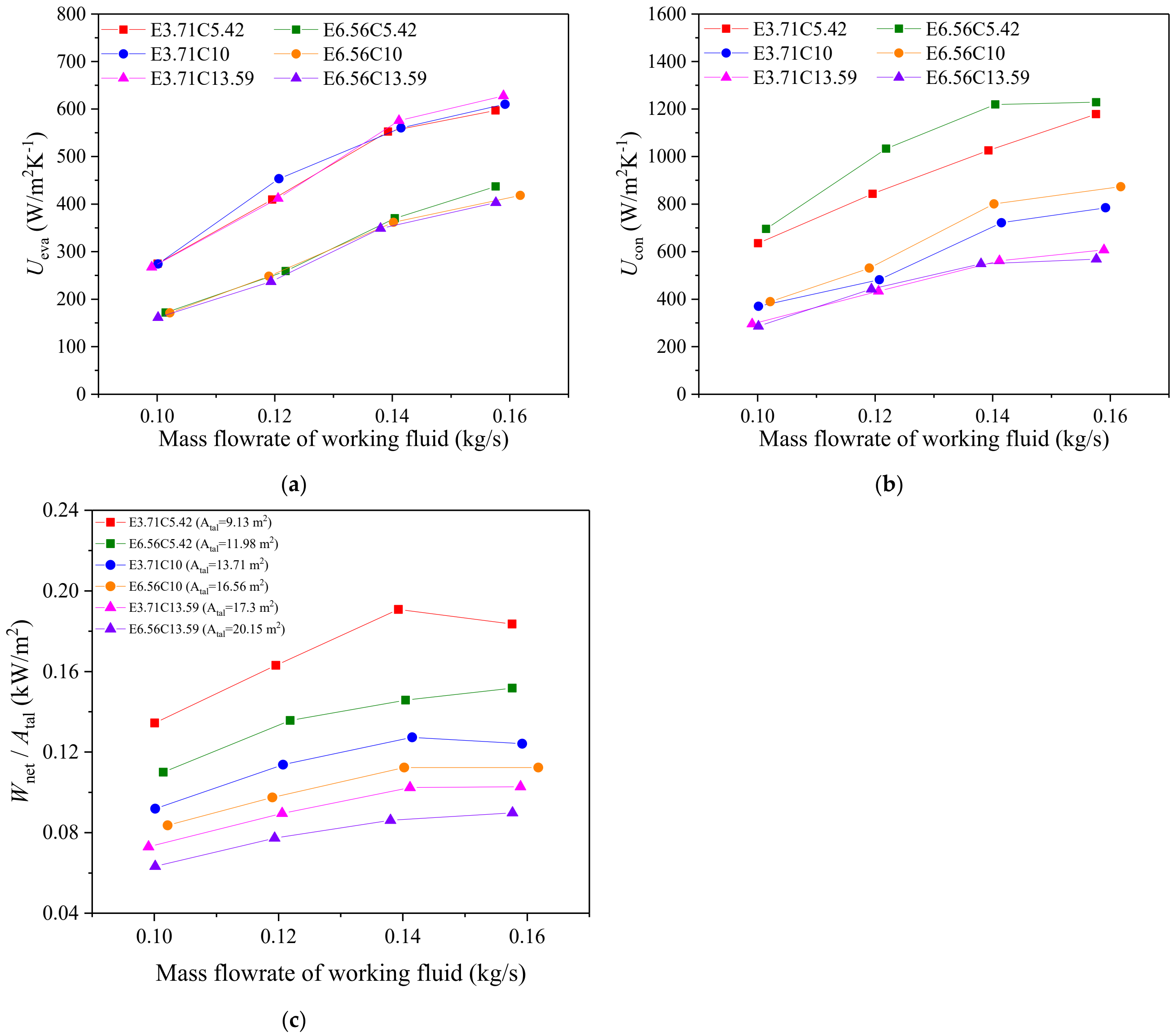


Figure 6. Operation behavior of different heat exchanger combinations: (**a**) overall heat transfer coefficient of evaporator; (**b**) overall heat transfer coefficient of condenser; and (**c**) heat exchanger area utilization of the ORC with different evaporator and condenser combinations [48]. Reproduced with permission from Zheng et al., Energy Conversion and Management; published by Elsevier, 2020.

3. Heat Transfer Enhancement and/or Novel Heat Exchanger Applied in ORC

In the previous section, the screening and comparison of distinct types and configurations of heat exchangers in the context of ORC were reviewed. Because of the significance of heat exchangers in the ORC, the application of routine heat exchangers is insufficient to meet the urgent requirement for a low-carbon or zero-carbon energy system. Accordingly, it is pressing and necessary to conduct research on heat transfer enhancement technology to enhance the performance of the heat exchanger and ORC. Several studies have been published on the investigation of innovative configurations of heat exchangers. Novel concepts for heat exchangers, which cover the innovation of materials [49], structures [23], and manufacturing [50], have been developed to reduce the weight, working fluid charge, and impact on the environment. In this section, the heat transfer enhancements and/or novel heat exchangers applied in ORC are reviewed from the perspective of component performance. The relevant performance enhancements via heat transfer enhancement and/or novel heat exchangers at the ORC system level are reviewed in Section 4.

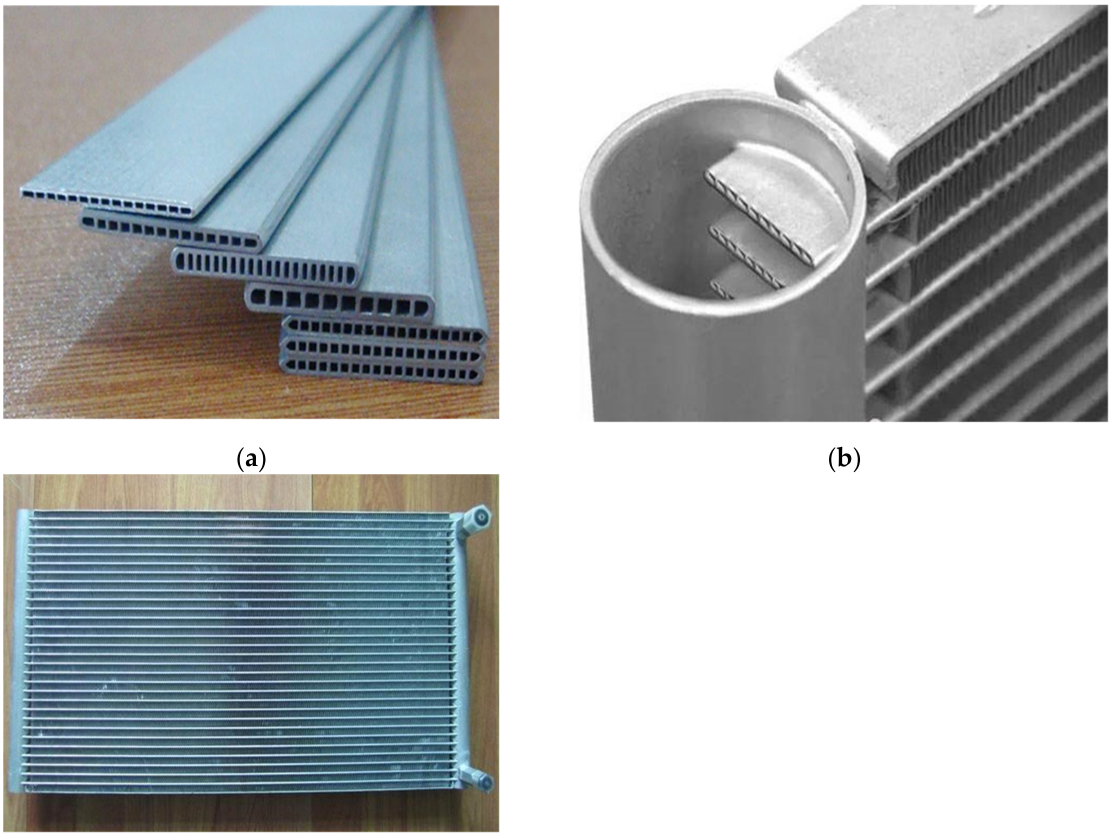
3.1. Innovative Material Used in the Heat Exchanger

Metal is the most-used material in the heat exchangers of thermal systems. Due to the rapid development of novel heat exchangers, new materials have recently been applied in the manufacturing of heat exchangers. Aláez et al. [51] evaluated the feasibility of replacing metallic heat exchangers with plastic components in a 20 kW ORC plant to reduce the investment cost. For one thing, due to the material stress limitations of the plastic heat exchanger, careful consideration must be given to the operating pressure of the working fluid. For another, considering the presence of corrosive heat sources such as geothermal water, the strength of the materials adopted in the evaporator should be boosted. Their analysis indicated that the investment costs can be significantly reduced if plastic heat exchangers are used in a small ORC plant. Compared with the ORC plant equipped with stainless steel heat exchangers, the cost of the produced electricity of plastic heat exchanger can be reduced by 6.60%. Kim et al. [52] proposed a novel plate evaporator by inserting high-porosity metal foams into plate channels to improve heat transfer and decrease the heat exchanger area. Then, Nematollahi et al. [53] experimentally investigated the operating performance of a brazed nickel foam plate heat exchanger in an ORC test rig. The results indicated that, compared with a commercial brazed plate heat exchanger under the same working conditions, the energy density of brazed nickel foam plate heat exchanger increased by 250%, while the pressure drop grew by 500%. However, the overall performance of the ORC was not negatively influenced. It is worth noting that the volume and the flow area of the brazed plate heat exchanger tested were one-third that of commercial brazed plate heat exchanger, which suggested positive prospects for the application of the brazed nickel foam plate heat exchanger.

3.2. Novel Structure or Arrangement of Heat Exchangers

In addition to the application of new materials, innovations in the structure or arrangement of heat exchangers are also one of the primary measures to improve heat transfer performance. Cao et al. [54] found out that tilting the horizontal arrangement of a shell-and-tube condenser can enhance the heat transfer rate. Thus, they suggested that the shell-and-tube condenser with a 30 degrees inclination angle makes it easier to trigger the churn flow pattern and stratified-wavy pattern featured by "turbulent", which is beneficial to the improvement of heat transfer performance of the condenser in the ORC system. Ravi et al. [45] designed an innovative double-pipe internally–externally protracted-finned counter flow heat exchanger and adapted it to an engine-ORC system. The heat transfer rate rose with the increase in fin numbers and lengths, which enhanced the performance of the ORC and raised brake thermal efficiency from 32% to 37%. In addition, a remarkable reduction in engine emissions was achieved because of the application of diesel oxidation catalyst coatings in the proposed novel heat exchanger. Zhang et al. [55] used a genetic algorithm to acquire the optimal nonuniform structure of a fin-and-tube evaporator. A star-shaped fin and elliptical tube were applied to enhance the performance of the evaporator in the ORC system. The windward area and the wake region behind the elliptical tube were smaller than that of a circular tube on account of the short windward radius, which was conducive to heat transfer enhancement and flow state improvement. In addition, they investigated a novel heat transfer enhancement technology using pulsating flow in Zhang et al. [56]. For the trans-critical ORC, Wang et al. [57] conducted an experimental comparison between an internally ribbed tube and a micro-finned tube used in a heat exchanger. According to the experimental data, they provided a more general tube selection criterion for the tube selection of the trans-critical ORC system.

The use of micro-channels in the heat exchanger of the ORC system is a promising technology due to its advantages in high heat transfer efficiency and compactness [58]. Figure 7 shows the structure of a condenser with a micro-channel. Mastrullo et al. [59] presented a novel design of an aluminum-made shell and louvered fin micro-channel tubes heat exchanger in an engine-ORC system. The micro-channel was carved into the flat tube to improve the heat transfer rate and decrease the working fluid charge, which exerts a positive influence on both the environment and safety. The results indicated that the proposed novel heat exchanger can maintain a relatively stable high efficiency of 80% under off-design conditions in the engine-ORC. The weight and space of the proposed louvered fin micro-channel tubes heat exchanger satisfied the requirements for on-road uses.



(**a**) (**b**) (**c**)

Figure 7. Structure of a micro-channel condenser: (**a**) porous micro-channel tube; (**b**) header; and (**c**) micro-channel condenser.

3.3. Liquid–Vapor Separation Concept Applied in the Heat Exchanger

The aforementioned reviews of novel heat exchanger structural improvements focus on surface enhancement without modifying the fluid flow direction, which limits the heat transfer enhancement ceiling. Liquid–vapor separation condensation is a newly developed heat transfer enhancement technology in which the two-phase working fluid is separated into vapor and liquid during condensation. The liquid working fluid is drained out while the vapor working fluid flows into the next pass with a high vapor quality, allowing for an improvement in the condensation heat transfer coefficient in the condenser. The pressure drop of working fluid in the condensing pass decreases simultaneously due to the decrease of the mass flow rate after the drainage of liquid working fluid. The advantages of the liquid–vapor separation condenser (LSC) over traditional condenser have been adequately validated through theory analysis and experiment [60–64]. The investigations have been further conducted on the application of liquid–vapor separation technology to different types of heat exchangers. Figures 8–10 display the schematic of different types of LSCs.

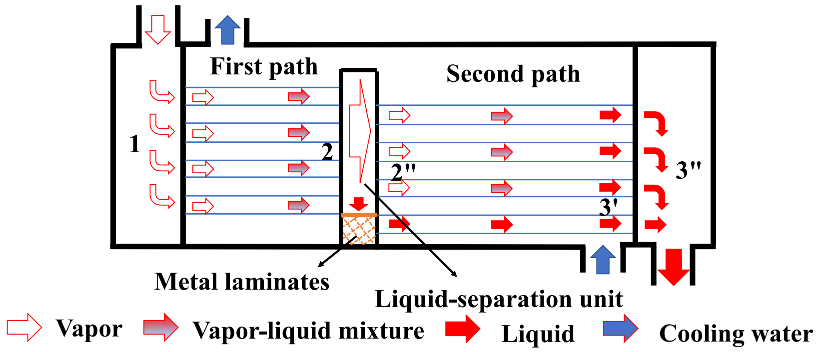


Figure 8. Model of a liquid–vapor separation shell-and-tube condenser [65]. Reproduced with per-mission from Li et al., Applied Energy; published by Elsevier, 2017.

Li et al. [65] applied the liquid–vapor separation condensation technology into a shell-and-tube condenser with two paths in a zeotropic ORC system and analyzed the impact of separation quality on the heat transfer performance. Figure 8 shows that the vapor and liquid fluid from the first flow path are separated in the liquid separation unit driven by the density difference. The liquid fluid falls into additional tubes through the holes on the metal laminates and the vapor is restrained by the liquid seals on the metal laminate surfaces. The results indicated that the liquid–vapor separation condensation technology can lead to a 23.8% increase in the average heat transfer coefficient compared to the conventional condenser under the same conditions. The optimal separation quality may be distinct for different mixture compositions. In their follow-up study, they found that the liquid–vapor separation condensation method was more appropriate to conditions involving a low cooling water temperature rise, small tube diameter, low inlet velocity inside the tubes, and high inlet velocity outside the tubes [66]. LSC is more effective in increasing the condensation heat transfer coefficient of zeotropic mixtures than that of pure fluids [67].

Figure 9 shows the liquid–vapor separated fin-and-tube condenser model [46]. Numbers of round bronze sheets with several orifices and non-uniform diameters utilized as baffles are set in the headers to drain the liquid from the liquid–vapor flow during condensation in the previous path, hence leaving only the refrigerant with high vapor quality to condense.

As depicted in Figure 10, Luo et al. [68] applied the plate type LSC to the zeotropic ORC system. A traditional plate condenser is separated into two paths by the liquid separation unit. In the first path, the working fluid flows into the odd-numbered channels, while the cooling fluid flows through the even-numbered channels. The liquid separation unit is installed at the bottom of the first path. The separated liquid fluid is drained out and the vapor enters the second path. In the second path, the vapor flows into the even-numbered channels, while the medium of the heat sink flows through the odd-numbered channels. The results indicated that, the temperature glide of the mixture increased after the liquid–vapor separation in the LSC, reducing the logarithmic mean temperature differences of the LSC. Figure 11 shows the heat transfer performance of plate type LSC in Luo et al. [68] and Lu et al. [69]. As shown in Figure 11a (The horizontal coordinate represents the normalized value of condensation, and the black dotted line represents the location of the liquid–vapor separation unit.), there is a sharp increase in overall heat transfer efficiency at the liquid–vapor separation unit. Thus, the condenser area of LSC is 11.6–17.6% smaller than that of a traditional condenser. Lu et al. [69] applied the plate type LSC as the upper structure of a composition adjustable unit in the ORC system (LCAZORC). As shown in Figure 11b (BZORC represents the basis ORC with conventional condenser, *HSIT* represents the heat sink inlet temperature, *EHTC* represent Equivalent heat transfer coefficient, the subscripts e and c represent the evaporator and condenser, respectively.), given that the mass flow of the heat sink is impacted by temperature glide of working fluid, the heat transfer efficiency of the LSC decreases due to the reduction of the heat-absorbed load in the ORC system. The

LSC had a 34.93% higher heat transfer efficiency than the conventional condenser because of the advantages of the LSC in heat transfer intensification.

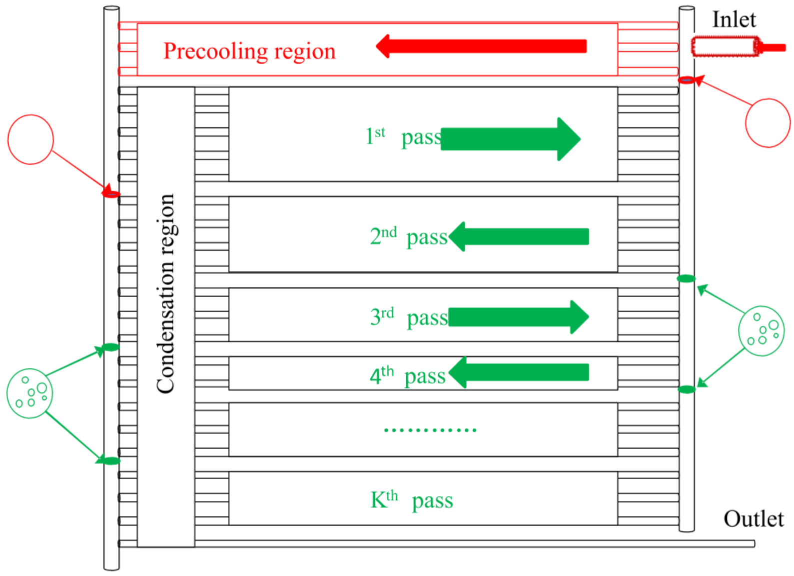


Figure 9. Model of a liquid-separated fin-and-tube condenser [70]. Reproduced with permission from Yi et al., Journal of Cleaner Production; published by Elsevier, 2018.

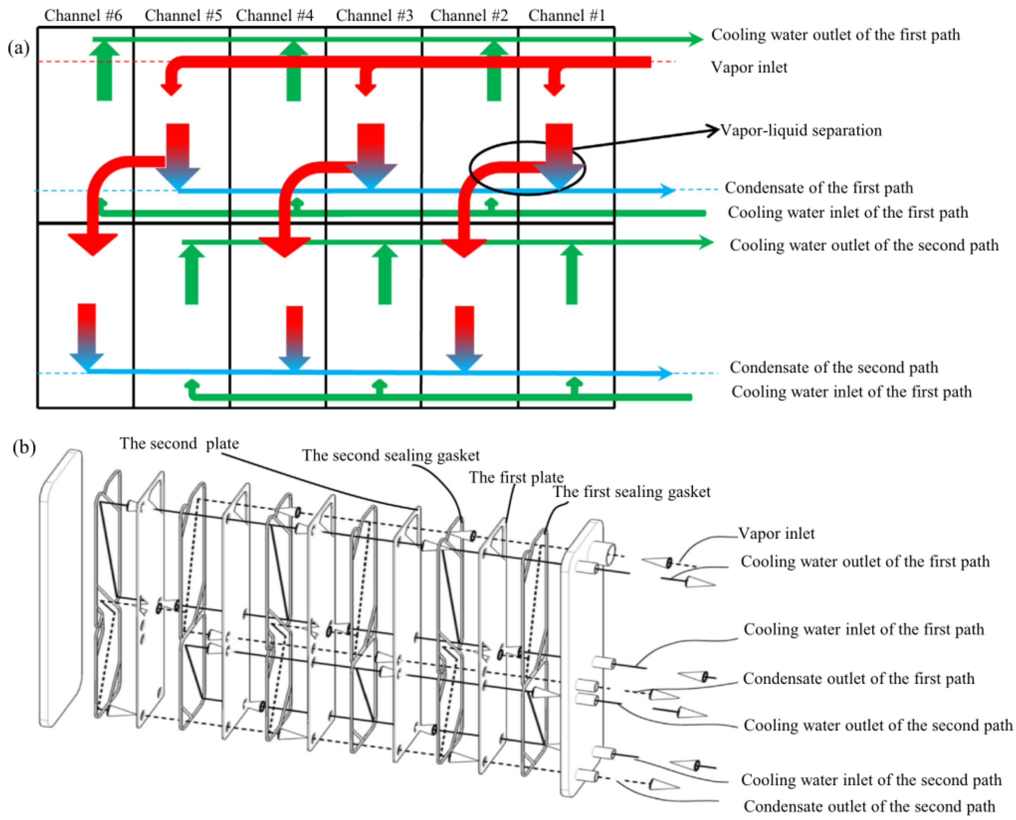


Figure 10. A plate type liquid-separation condenser: (**a**) schematic; and (**b**) conceptual designed configuration [68]. Reproduced with permission from Luo et al., Energy Conversion and Management; published by Elsevier, 2017.

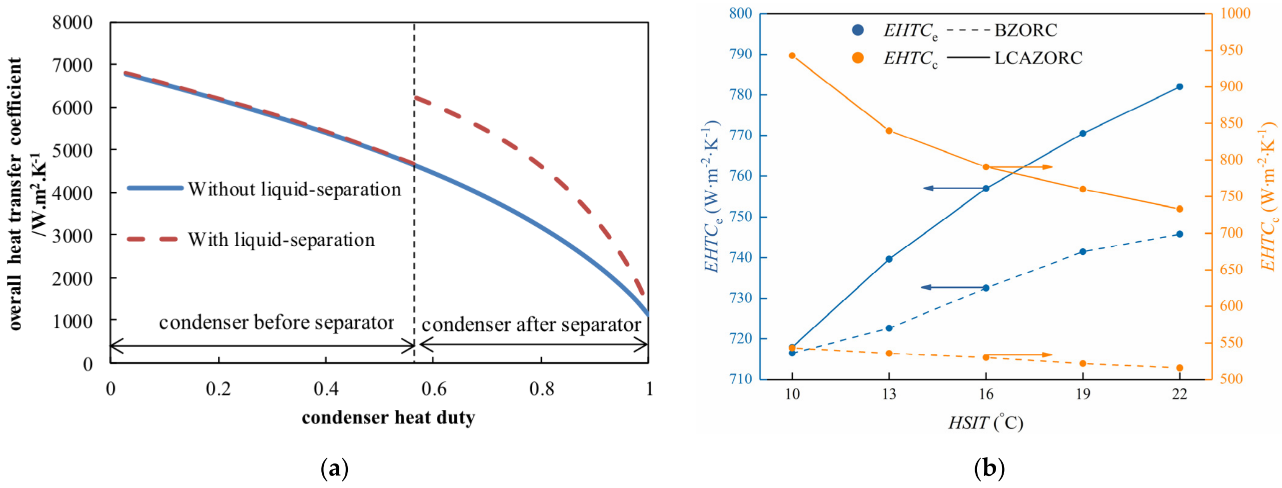


Figure 11. Heat transfer efficiency of plate-type LSC from: (**a**) Luo et al. [68] Reproduced with per-mission from Luo et al., Energy Conversion and Management; published by Elsevier, 2017; and (**b**) Lu et al. [69]. Reproduced with permission from Lu et al., Energy Conversion and Management; published by Elsevier, 2020.

Table 1 shows tabularized information about the various research studies on heat transfer enhancements and/or novel heat exchangers. Current research on novel heat exchangers in the ORC system mainly focuses on theoretical calculations and simulations. Even though the thermo-economic performance of the different types of heat exchangers has been extensively demonstrated, there are few reports on the experimental research or practical applications of novel heat exchangers. This is an important direction for heat transfer enhancement in the heat exchangers of ORC systems in the future, which may lead to a significant advancement with regard to ORC systems in practical applications.

Table 1. Relevant research on the heat transfer enhancements and/or novel heat exchangers.

Ref.	Method	Index	Benefit
[51]	Plastic manufacturing	Cost of the produced electricity	Reduce 6.60%
[52]	Inserting high-porosity metal foams	Component volume	Reduce 33.33%
[45]	Using double-pipe internally-externally protracted-finned counter flow	Thermal efficiency of ORC	Enhance 5%
[59]	Using micro-channel	Heat transfer rate	Maintain 80%
[68]	Using liquid–vapor separation	Heat transfer are	Reduce 11.6–17.6%
[69]	Using liquid–vapor separation	Equivalent heat transfer coefficient	Enhance 34.93%

4. ORC Performance Enhancement via Heat Transfer Enhancement Technology or Novel Heat Exchanger

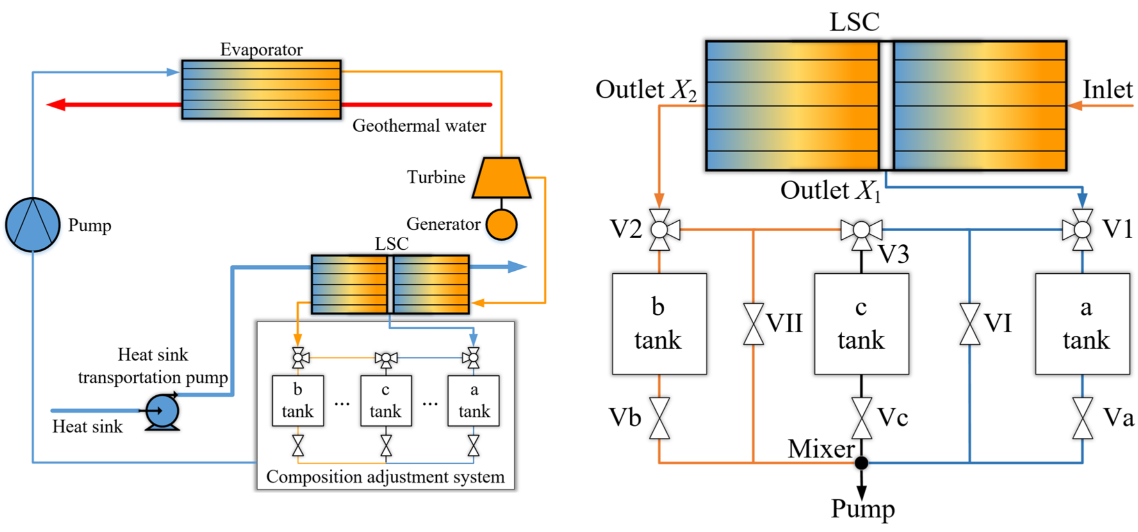
To further increase ORC system performance, scholars have tried to utilize a novel heat exchanger in the ORC. It was noted in the previous section that each novel heat exchanger has a unique heat transfer characteristic depending on its inner structure and application (e.g., evaporator, condenser, and recuperator) [71]. Moreover, the application of a novel heat exchanger in the ORC is bound to influence the ORC system structure, and as a result the ORC system will exhibit some new operating characteristics [33,48,68]. Hence, it is necessary to review the ORC with a novel heat exchanger to clarify the enhancement of the novel heat exchanger in system performance. The studies of novel heat exchangers used in ORCs with different configurations, such as basic ORC and dual/multi-pressure evaporating ORC, are reviewed from a thermal system perspective.

4.1. ORC with Novel Heat Exchangers

A lot of studies have focused on the design and optimization of novel heat exchangers in the ORC system. The application of novel heat exchangers, such as the shell and louvered fin mini-tubes heat exchanger [59], brazed metal-foam plate heat exchanger (BMPHE) [53], fin-and-tube heat exchangers with the enhanced structures of fin and tube [55,57], and evacuated flat plate photovoltaic-thermal collector [72], showed a preferable performance improvement in the ORC systems. Mastrullo et al. [59] reported that the utilization of a novel fin and mini-tube heat exchanger increased overall system efficiency by up to 9%. Nematollahi et al. [53] discovered that the performance of the ORC system was not remarkably improved, but the power density increased by 2.5 times when the BMPHE was utilized in the ORC.

Liquid–vapor separation condensation is a promising technology that may simultaneously achieve improvement in the heat transfer coefficient and reduction in the pressure drop of the condenser. During the condensation, the liquid portion of working fluid can be discharged, thereby reducing the liquid film thickness and improving the vapor quality of condensate simultaneously. The liquid–vapor separation condensation technology has been widely applied in ORC and refrigeration systems, with notable improvements in thermodynamic and thermo-economic performance [63,67]. Luo et al. [73] proposed a pass-by-pass tube side modeling method for the LSC design, taking into account the impacts of pass number, tube number, fin number, tube-fin type and investment cost. Then, Luo et al. [46] applied the LSC in the ORC and conducted a performance comparison of the LSC, parallel flow condenser (PFC) and serpentine condenser (SC). They found that the thermal efficiency and exergy efficiency of the ORC using LSC- were 13.75% and 11.82% higher than those of the ORC using SC-, respectively. Next, they [68] utilized the zeotropic mixture in the LSC-based ORC and revealed that the specific investment cost of the proposed ORC was reduced by 13.3–18.4% compared with the conventional ORC. Yi et al. [74] developed a novel mathematical modeling method for the LSC-based ORC and optimized the configurations of components and operating parameters of system simultaneously. Results illustrated that the electricity production cost of the LSC-based ORC was decreased by 12.29%. Their subsequent work paid attention to the –multi-objective optimization of the LSC-based ORC to obtain a trade-off solution considering thermodynamic, economic and environment performance, and a comprehensive evaluation framework that included a life-cycle inventory of raw materials was reported [70].

Luo et al. [75] found that the compositions of the vapor and liquid that separated from the LSC are different in the zeotropic ORC system. Thus, Lu et al. [69] proposed a novel LSC-based- zeotropic ORC system with composition adjustment. The composition adjustment, which can achieve a better heat matching for a stable long-term off-design operation and the expansion ratio adjustment of the expander, is an important application of LSC that contributes to the improvement in system performance. Lu et al. [69] designed an LSC-based unit combining the heat transfer enhancement and mixture composition adjustment, tuning them conceptually and integrating the unit into a zeotropic ORC, called LCAZORC. As shown in Figure 12, the composition adjustment system consists of a storage tank that regulates the mass flow rate and two buffer tanks that adjust composition. It is noted that the buffer tanks can be utilized to reserve or supply a mixture at each operation period. A tailored algorithm and sequential method were developed to carry out the component design, thermodynamic and thermo-economic optimization of the proposed ORC. They found that the proposed ORC increased the annual average W_{net} by 0.52%, the annual average thermal efficiency by 2.20%, and reduced the average electricity production cost by 21.43%, compared with the conventional ORC.



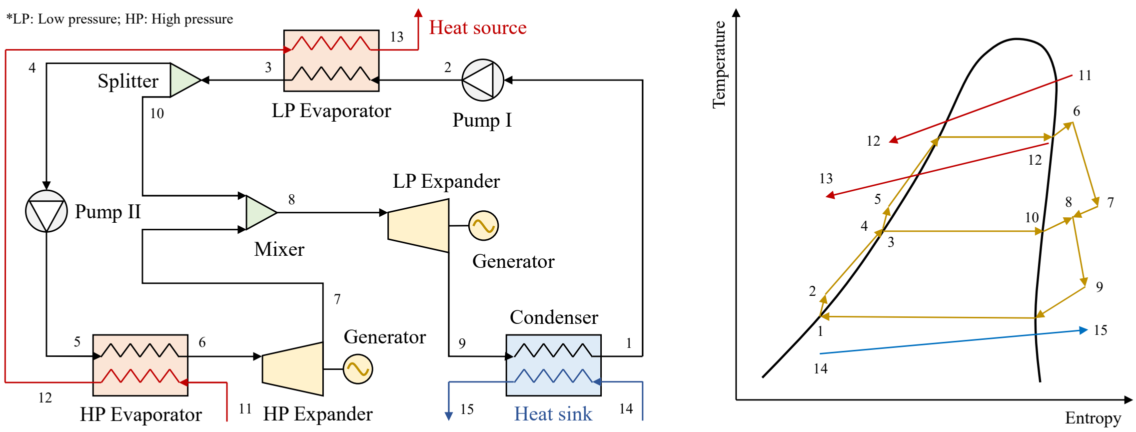
(**a**) (**b**)

Figure 12. (**a**) Schematic of LCAZORC; and (**b**) representation of a three-tank LSC-based composition regulation system [69]. Reproduced with permission from Lu et al., Energy Conversion and Man-agement; published by Elsevier, 2020.

In summary, the application of novel heat exchangers in the ORC system has proven to be a promising measure to achieve performance improvements. The heat transfer coefficient of the novel heat exchanger can be improved mainly because of the increase in the heat transfer area and the enhancement in stream disturbance. The performance of the LSC-based basic ORC systems was superior to that of the ORC systems with conventional heat exchangers.

4.2. Dual/Multi-Pressure Evaporating ORC

Unlike the basic ORC, the dual/multi-pressure evaporating ORC with more than one evaporating stage leads to better matching between the working fluid and heat source, mainly due to the decline in the heat transfer temperature difference [76,77]. Figure 13 gives an example of the dual-pressure evaporating ORC flowsheet and the corresponding temperature-entropy diagram. Recently, the liquid–vapor separation condensation method from the condenser side and partial evaporation from the evaporator side, as the two promising technologies for system performance improvement, have received considerable attention for the dual/multi-pressure evaporating ORC.

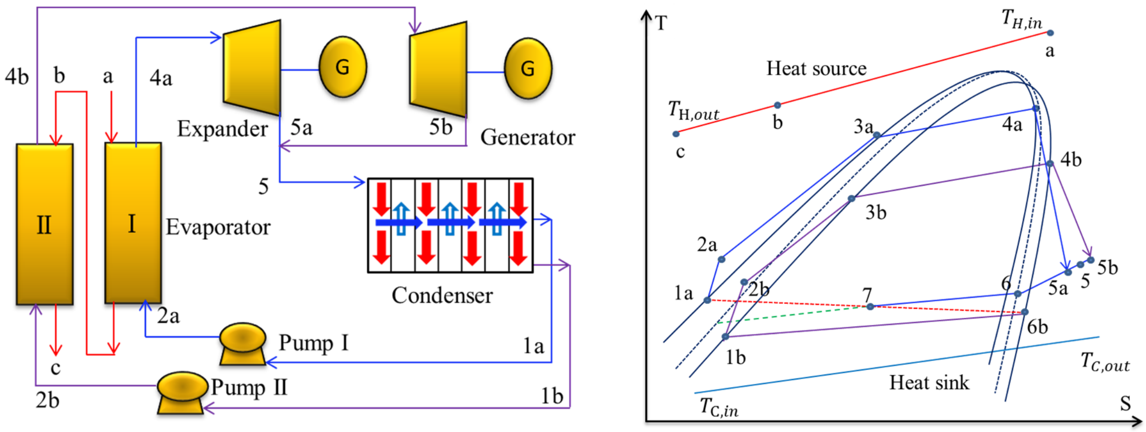


(**a**) (**b**)

Figure 13. Diagrams of dual-pressure evaporating ORC: (**a**) System configuration; (**b**) Cycle process.

4.2.1. Dual/Multi-Pressure Evaporating ORC with Liquid–Vapor Separation Condensation Method

Luo et al. [75] proposed a novel dual-pressure evaporating ORC, coupling the LSC and zeotropic mixture (LMZORC). Regarding the LMZORC, the condensate stream is first separated into two streams in the LSC and then the two streams are pumped into different pressures, as shown in Figure 14. From the viewpoint of thermodynamic performance, the LMZORC clearly outperforms both the traditional simple zeotropic ORC and the dual-pressure evaporating zeotropic ORC. The increment in W_{net} reached 13.05–26.18% in the case studies. They demonstrated that the involvement of LSC was beneficial to the thermodynamic performance improvement for the dual-pressure evaporating ORC, primarily because the composition and mass flow rate of streams at different pressures can be regulated by the effective quality adjustment in the LSC. They specifically analyzed the influence of various levels of economic improvement (DLEI, the relative improvement of heat transfer coefficients of the LSC compared to the same type of condenser without liquid separation) on the LMZORC's performance under the same specific heat exchanger area. As shown in Figure 15, the LMZORC achieved an 8.22% increase in W_{net}, compared with the dual-pressure evaporating ORC without LSC.



(**a**) (**b**)

Figure 14. Diagrams of LMZORC: (**a**) system configuration; and (**b**) cycle process [75]. Reproduced with permission from Luo et al., Energy Conversion and Management; published by Elsevier, 2018.

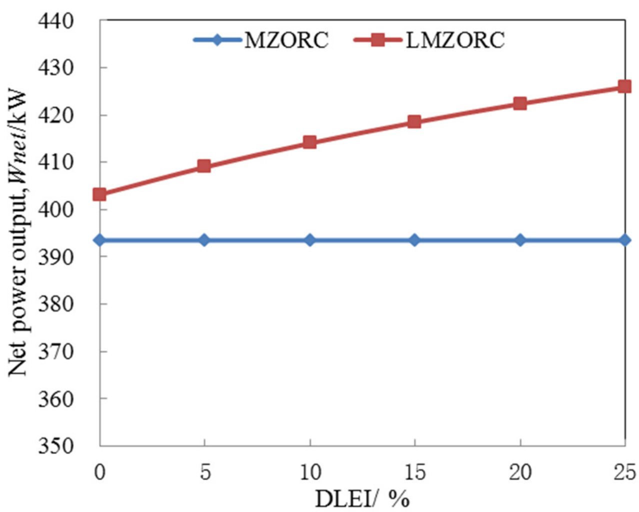


Figure 15. W_{net} of LMZORC and MZORC at different DLEIs [75]. Reproduced with permission from Luo et al., Energy Conversion and Management; published by Elsevier, 2018.

To further evaluate the influence of heat exchanger structure on the dual-pressure evaporating ORC's performance, Li et al. [66] studied a dual-pressure evaporating ORC with LSC based on two levels, namely, a shell-and-tube condenser (component) and ORC (system). At the component level, they pointed out that the low inlet velocity in the tubes, high inlet velocity outside the tubes, short tube diameter, and low cooling water temperature rise were advantageous to the application of the liquid-separated condensation method in the condenser. At the level of the system, the ORCs with LSC can reduce the specific investment cost by 2.8–4.6% compared with ORCs without LSC under design conditions.

Zhang et al. [78] applied the LSC to a dual-pressure evaporating ORC for ocean thermal energy conversion. They conducted a comparative analysis of the traditional zeotropic ORC and other six zeotropic ORCs with different types. The results proved that the improved performance of the dual-pressure evaporating ORC with LSC results from the increase in the heat transfer coefficient. The dual-pressure evaporating ORC with LSC can increase W_{net} by 1.48% and reduce the levelized cost of electricity (*LCOE*) by 3.40% in contrast to the ORC without LSC.

To sum up, the heat transfer coefficient improvement in LSC than traditional condenser is primarily attributable to the timely drain-off of the condensate and the appropriate tube and pass arrangement. A better matching between the working fluid and heat sink is expected on account of the change of cooling duty. As stated previously, the use of a zeotropic mixture in the multi-pressure ORC with LSC is usually well accepted to further improve the thermodynamic performance, especially by reducing the irreversibility during the condensation process. However, previous studies only focused on the performance comparison and evaluation of the predefined combination of the multi-pressure evaporating ORC, zeotropic mixture, and LSC. Thus, it is necessary to complete the model framework, including the LSC geometrical optimization, ORC operating optimization, and highly accurate thermophysical properties and heat transfer models of zeotropic mixtures to realize simultaneous optimization and system configuration design.

4.2.2. Dual/Multi-Pressure Evaporating ORC with Partial Evaporation

Partial evaporation improves the structure of the multi-pressure evaporating ORC from the evaporation side by optimizing the energy distributions among different heat exchangers [79]. Relevant research on the partial evaporating multi-pressure ORC can be found in Table 2. As far as we know, the multi-pressure evaporating ORC usually utilizes a rejector, vapor regenerator and separator to achieve partial evaporation. Moreover, the examined working fluids are mostly concentrated in pure fluids because it is challenging to accurately assess the zeotropic mixture composition of liquid and vapor portions after separation. Figure 16 shows the cycle architecture based on the partial evaporation and the corresponding temperature–entropy diagram. An important parameter that determines the ORC performance is vapor quality, which has a significant impact on how the energy is distributed among evaporators.

Table 2. Relevant research on the multi-pressure ORC based on partial evaporation.

Ref.	Working Fluid	Partial Evaporating Type	Performance
[80]	Cyclopentane	Vapor regenerator	Thermodynamics
[81]	R245fa, R236ea, R600, R600a, R601, R601a	Separator	Thermodynamics, Thermo-economics
[79]	Propane, R227ea, R152a, R124, R142b, Butane, R245fa, R601a	Separator	Thermodynamics
[82]	Cyclopentane	Ejector/Vapor regenerator	Thermodynamics
[83]	R600, R600a, R601, R601a, R1234ze	Separator	Thermodynamics, Techno-economics

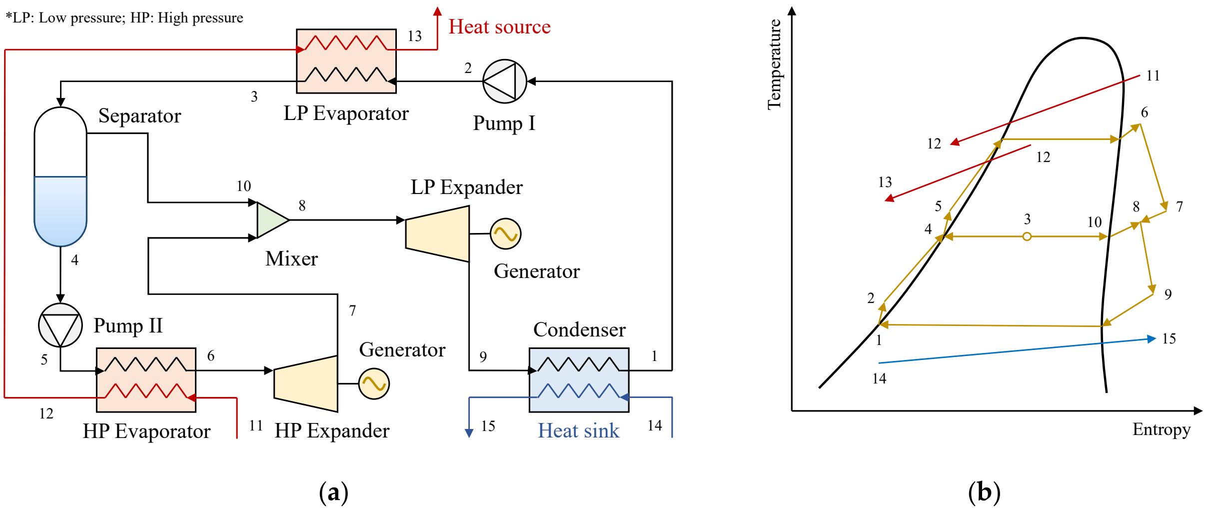


Figure 16. Diagrams of partial evaporating multi-pressure ORC: (**a**) system configuration; and (**b**) cycle process.

Li et al. [79] proposed a novel partial evaporating dual-pressure ORC based on the separator (PEDORC). The influences of evaporating temperature, vapor quality, and degree of superheating temperature on the thermodynamic performance were analyzed, and the multi-parameter optimization of PEDORC was also conducted in Li et al. [79]. The results showed that the PEDORC achieved up to 9.2%, 4.0%, and 0.86% increases in W_{net}, exergy efficiency, and thermal efficiency respectively, compared with the conventional dual-pressure evaporating ORC (DORC). Thus, they considered the PEDORC system a promising alternative scheme for the DORC because it effectively distributes the energy input for the two evaporators, reducing the irreversibility of heat transfer.

Surendran et al. [82] added an ejector to the working fluid mixing process of DORC and designed a new system called trans-critical ejector regenerative series two-stage organic Rankine cycle (TER-STORC). They also proposed two operating modes, namely partial evaporation (PE) and full evaporation (FE) for the TER-STORC. The performance of the TER-STORC operating in FE mode was similar to the DORC, and the heat exchange load requirement of TER-STORC was decreased by up to 18%, reducing system complexity.

In conclusion, adopting partial evaporation can further suitably distribute the heat input of each evaporator, and raise the thermodynamic and economic performance of the ORC. However, the ORC with partial evaporation requires precise control of two-phase flows because the quality significantly affects system performance. In addition, the liquid carryover caused by heat input fluctuations leads to corrosion of the turbine blades, especially for dual/multiple heat sources. Consequently, it is indispensable to develop a tailored control strategy for the real-time operation of multi-pressure evaporating ORCs with partial evaporation. Moreover, an accurate model framework is also required to monitor the operating characteristics that fluctuate with the environment.

4.2.3. Dual/Multi-Pressure Evaporating ORC Integrates Liquid–Vapor Separation Condensation and Partial Evaporation

Liquid-separated condensation and partial evaporation, as the two main measures to improve the system performance, reconstruct the ORC structure from the condenser and evaporator sides, respectively. However, few studies in the literature have focused on the ORC with liquid–vapor separation condensation and partial evaporation simultaneously on account of the complexity of the structure and operating controls. To the best of our knowledge, Huang et al. [84] first proposed an ORC integrating LSC and ejector (LEORC), as shown in Figure 17. The ORC implements the LSC to separate the composition of the zeotropic mixture, and the composition is mixed again in the ejector. It is noted that a four-way valve was used to direct the liquid zeotropic mixture with different compositions to different processes and thus, two operating modes were developed. They conducted a comparison between the LEORC and LMZORC proposed by Luo et al. [75] and found that the LEORC was advantageous to LMZORC in terms of an average increase in W_{net} of 3.36–8.48%, and the power consumption of pump for the LEORC was reduced by 21.6%. Figure 18 presents the comparison results between LEORC and LMZORC using R600a/R601 in Huang et al. [84]. Furthermore, they evaluated the influence of entrainment ratio and heat source/sink inlet temperature on system performance for the LEORC operating in different modes and summarized the preferred operating conditions of each mode. As reviewed above, different from the traditional DORC using a zeotropic mixture, the LEORC achieved efficient heat exchange between the heat source and working fluid composition at different pressures by adjusting the composition in accordance with the heat exchange characteristics of compositions with different boiling points, The research facilitates the research of dual-pressure evaporating ORC system with a new idea.

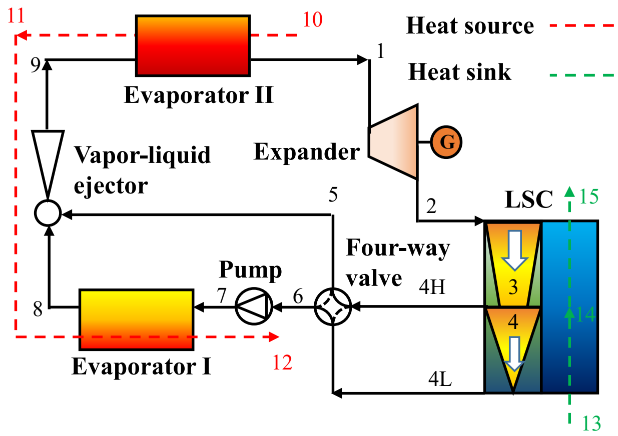


Figure 17. System configuration of LEOCR [84]. Reproduced with permission from Huang et al., Energy; published by Elsevier, 2022.

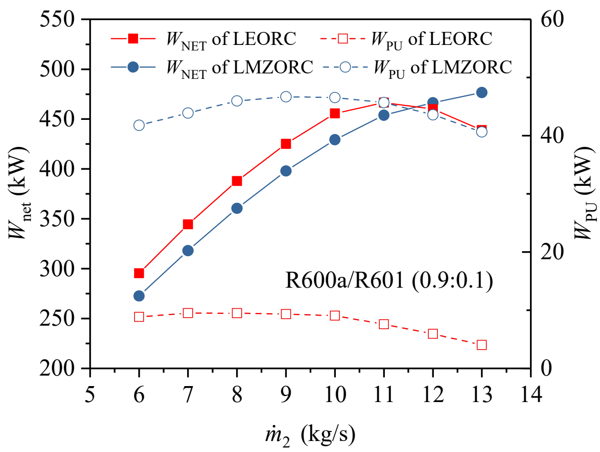


Figure 18. Performance comparison between LEORC and LMZORC [84]. Reproduced with permission from Huang et al., Energy; published by Elsevier, 2022.

To sum up, novel heat exchangers have been widely applied in the ORC systems with satisfactory performance improvements. Especially, the liquid–vapor separated condensation technology and partial evaporation method are expected to gain more application value in ORC systems. However, the quality and composition should be well controlled during evaporation and condensation. Therefore, the composition adjustment adds complexity to ORC systems. The type and fluctuations of heat sources, the working fluid as well as the system configuration have great impacts on the performance of the ORCs with the LSC, flash evaporator or ejector. Precise dynamic control and reliable performance prediction need to be further developed to ensure that the system operates with high efficiency, flexibility, and stability.

5. Design and Optimization of Heat Exchanger and ORC System

Due to the complex correlation and coupling of the structural and operating parameters between the heat exchanger and ORC system, it is hard to guarantee the optimal design scheme. Optimization is a well-accepted approach for achieving the optimal schemes of heat exchanger and ORC system. The design modelling, heat transfer correlation, and optimization algorithm are indispensable parts in the optimization process for heat exchanger and ORC system. Many scholars have conducted in-depth research on the optimization of heat exchanger and ORC system.

5.1. Design Modelling of Heat Exchanger

Because the difference between the condensation and evaporation temperature is relatively smaller, the overall performance of the ORC system is significantly affected by the environmental parameter fluctuation. Thus, the heat exchanger design that aims to achieve an optimal life-span system performance is a complicated process because of the complexity of the interactions among the heat transfer characteristics, environmental parameters, and the structural parameters. Walraven [36] pointed out that the majority of ORCs were designed based on past experience, which usually deviates a lot from the optimal configuration. To effectively design a heat exchanger, the production cost, temperature ranges, pressure limits, pressure drop, fluid flow capability, thermal efficiency, cleanability, materials, maintenance, and other factors are also necessary and should be given due regard [23]. Therefore, the development of the ORC system surely calls for an efficient heat exchanger design tool that effectively solves the complexity and instability at the design stage.

Several studies investigating various heat exchanger designs are presented in Table 3, which can be divided into two categories [85]. The first category places emphasis on the optimal design of the geometry under steady-state design conditions without considering the thermal inertia and therefore ignores transient phenomena. The finite element method based on equal enthalpy or volume difference, which is one of steady-state design modelling method, is commonly used -for detailed analysis of the heat transfer behaviors of the heat exchanger in the ORC. In the ORC heat exchanger design, the applications of the commonly steady-state design modelling method appear in the field of supercritical fluid applications [86], structural parameter optimizations [44], micro-channel dimension decisions [87], experimental validation and simulations [87], and renewable energy-driven-ORCs [88]. Karellas et al. [86] noted that it is essential to study the relatively unknown heat transfer mechanisms around the critical point, which required a much larger heat transfer area to improve the heat exchanger surface. Then, they offered a handy and accurate tool for future research in this field. Wajs et al. [87] presented a novel design and manufacture method of the shell-and-tube condenser with a micro-channel for the ORC system. The calculations of the convective heat transfer coefficient for the proposed micro-channel condenser were accomplished based on a semi-empirical model developed from the experiment. Finally, an experimental validation of the proposed prototype construction was completed in a micro-ORC installation. Wajs et al. [87] presented a complete process for designing and testing the heat exchangers. In general, the steady-state design model is suitable for ORC running under relatively stable boundary conditions, which pursue effective heat transfer and reflect the overall energy efficiency.

The second category concentrates on dynamic models of the heat exchangers, guiding the prediction of dynamic operation for control purposes in the ORC. These design modelling methods, which often rely on dynamic modules in commercial software, attempt to simulate the real heat transfer behaviors of the heat exchanger in response to the fluctuant heat source/sink. The most common application scenario is the heat exchanger design in the engine-ORC system [89]. Whether to prevent the fluctuation of the heat source and to protect the integrity of the working fluid, or to obtain an easily controlled system, the traditional steady-state heat exchanger design methods do not adapt to engine-ORC suitably because of the specific large-gradient temperature drop and fluctuation of engine waste heat. Zhang et al. [90] provided a useful method to design a fin-and-tube evaporator in an engine-ORC. First, they assessed the exhaust heat of the diesel engine to obtain the measured data. Then, a mathematical model of the evaporator was created based on detailed geometry and specific ORC working conditions. Finally, the heat transfer behaviors were estimated, and the operating regions of the evaporator were defined by the engine speed and the load. The results showed that the heat transfer area is affected by the engine's most typical operating region, which should be selected carefully. Jiménez-Arreola et al. [85] pointed out that taking into account the thermal response time of the evaporator at the design stage is important due to the highly dynamic operation under fluctuating waste heat sources. The "response time" was defined as a key factor for systematically evaluating the thermal inertia of an ORC evaporator in the study by Jiménez-Arreola et al. [85]. They provided a dynamic-state design method, depicted in Figure 19, to bridge the gap between the optimal evaporator design and its behavior under dynamic conditions, thereby guiding a custom design of the dynamic behavior of the ORC system. Lastly, they demonstrated that the design geometry is contingent on the operational characteristics at a given time.

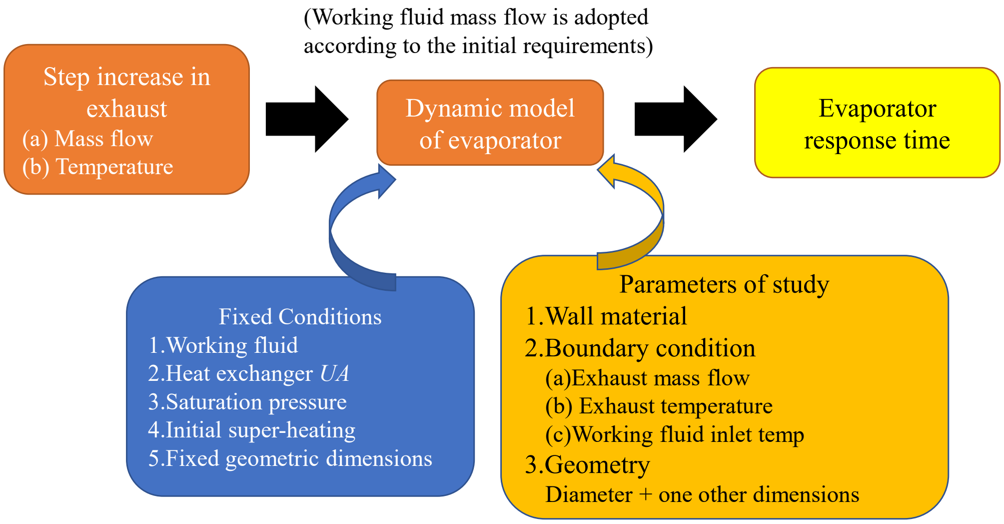


Figure 19. Summary of dynamic characterization methodology [85]. Reproduced with permission from Jiménez-Arreola et al., Applied Energy; published by Elsevier, 2018.

Overall, these two heat exchanger design methods can effectively address complex problems in the design process. The relationship between the heat transfer performance of the heat exchanger and its geometry and operating conditions can be quickly obtained by the steady-state design method. However, the steady-state design is only appropriate for ORC systems under relatively stable working conditions. It cannot reflect the thermal inertia of the heat exchanger under off-design working condition changes to guide the design of the control strategy of the ORC system. Dynamic design methods can prevent heat exchanger performance loss under off-design conditions, which is a more promising design method. However, this method currently relies on commercial software, and its solution accuracy is dependent on the number of grids. High-precision design will prolong the design time and increase the cost of design. Because of the fluctuating operation of the ORC system, the dynamic heat exchanger design method will have more development potential. A heat exchanger design model with high precision and versatility for the comprehensive design of ORC systems remains one of the future's most important trends.

5.2. Heat Transfer Correlation

The high precise heat transfer correlation (*HTC*) can effectively reveal the real heat transfer characteristics, which are affected by the categories of working fluids, operating conditions, and structural parameters of heat exchangers. Thus, the investigation of heat transfer characteristics in the ORC serves as the foundation for research on heat exchanger design, performance enhancement, and optimization directions. On account of the relatively high evaporation temperature in the ORC, the high-temperature flow boiling heat transfer experiments for organic working fluids and their corresponding correlations are an important part of the development of the heat exchanger and the ORC system.

Bao et al. [91] reviewed the research on the working fluid selection for ORC and summarized the recommended working fluids, including both pure working fluids and mixed working fluids. Many scholars have carried out different flow boiling heat transfer experiments for these working fluids and developed corresponding correlations. Charnay et al. [92] studied the two-phase flow pattern of R245fa within an inner diameter of 3 mm horizontal circular tube and an evaporating temperature between 60 °C to 120 °C. The results showed that as the evaporation temperature rises, the liquid film thickness at the bottom increases gradually and the local dry-out occurs in lower vapor quality. Furthermore, the annular flow occupied a narrower vapor quality range while the range for intermittent flow and the mist flow becomes larger. In addition, as the blood of the ORC, mixed working fluids have attracted extensive attention from scholars because they more easily meet the demands of thermodynamic performance, environmental protection, and safety than pure working fluids [93]. As shown in Figure 20, the temperature glide enables the improvement of the heat match between the working fluid and heat source [94]. However, the mass transfer resistance of the zeotropic mixtures leads to the deterioration of heat transfer. Guo et al. [95] studied the flow boiling heat transfer characteristics of R245fa/R134a (0.67:0.33) in a horizontal tube with an inner diameter of 10 mm and an evaporating temperature of 55–95 °C. The results showed that, due to the mass transfer resistance, the *HTC*s of the zeotropic mixture were much lower than that of R134a and closer to that of R245fa. Zhang et al. [96] experimentally studied the condensation heat transfer characteristics of R134a/R245fa in a plate heat exchanger. By comparing the experimental data with linear interpolation values of pure fluids, they stated that the heat transfer of the zeotropic mixture deteriorated, and the *HTC* could be reduced by up to 48% because of the mass transfer resistance.

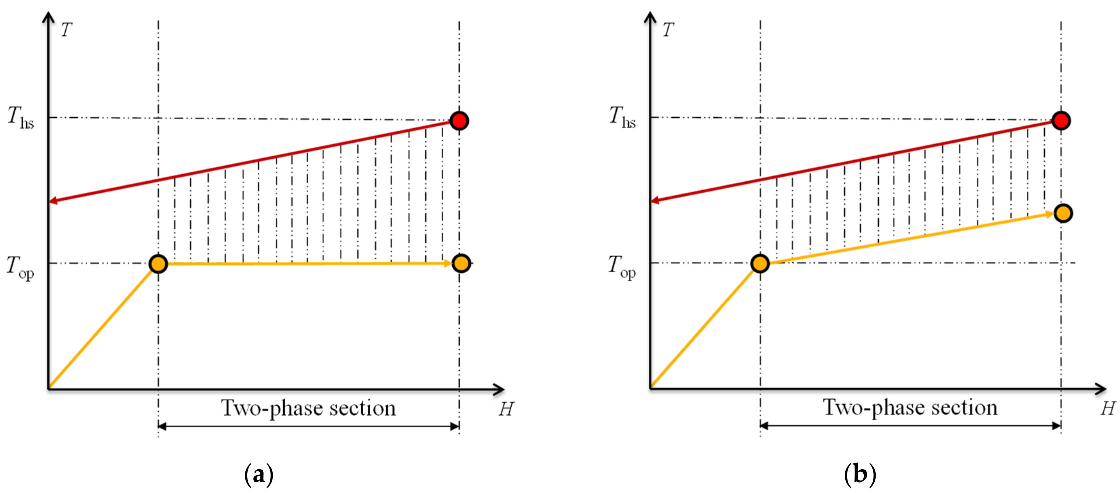


Figure 20. Heat exchange process between working fluid and heat source in evaporator of the ORC: (**a**) pure fluid; and (**b**) zeotropic mixture.

Table 3. Some design investigations conducted on different types of the heat exchangers.

Ref.	Types	Methods	Challenges	Applications
[86]	Plate heat exchangers	Finite element method based on equal enthalpy difference	Component selection aiming at minimizing cost	Under supercritical conditions
[44]	Plate condenser	-	Evaluating the effect of plate spacing on operating performance	Common approach
[97]	Plate heat exchangers	1D pressure-enthalpy based discretized method	Determining the dimension of the heat exchangers	Common approach
[90]	Fin-and-tube evaporator	Finite element method based on equal enthalpy difference	Evaluating the off-design operating performance	Engine exhaust heat recovery
[85,98]	Fin-and-tube evaporator	Finite element method modeled in the commercial software Dymola using the commercial TIL library	Dynamic time response	Engine exhaust heat recovery
[99]	Fin-and-tube evaporator	CFD simulation model modeled in the commercial software Fluent	Evaluating qualitatively the thermal-hydraulic characteristics	Engine exhaust heat recovery
[100]	Fin-and-tube evaporator	Finite-volume dynamic model	Dynamic time response	Heavy-duty vehicle waste heat recovery
[40,41]	Fin-and-tube or shell-and-tube evaporator	1D Finite-volume dynamic model modeled in the commercial software Dymola using the commercial TIL library	Dynamic time response	Engine exhaust heat recovery
[101]	Shell-and-tube heat exchanger with double-segmental baffles	Finite-volume dynamic model modeled in the commercial software DYMOLA 2015 FD01	Experimental validation	Single phase flow
[88]	Shell-and-tube heat exchangers	Logarithmic mean temperature difference method and a two-stage Taguchi method	Evaluating the influence of the solar irradiation intensity on the optimum design parameters	Solar ORC
[102]	Shell-and-tube pool boilers	Finite-volume dynamic model	Dynamic time response	Common approach
[87]	Shell-and-tube condenser with micro-channel	Semi-empirical model	Experimental validation	Micro ORC

In summary, the aforesaid research demonstrates that different working fluids, evaporation temperatures, and pipe diameters have a great impact on flow boiling heat transfer characteristics. Zeotropic mixtures can improve ORC performance, but the poor heat transfer characteristics limit their application. However, little research has been conducted on heat transfer characteristics at the temperature range that is suitable for ORC evaporation. Figure 21 shows the distribution of experimental conditions of the flow boiling heat transfer characteristics of the ORC-recommended working fluid from Bao et al. [91]. The testing conditions of the ORC-recommended working fluids are mainly concentrated on the small pipe diameter and low evaporating temperature range. The research on large pipe diameters and high evaporating temperatures, which are typically employed in the ORC, is relatively limited [103]. Moreover, there is a dearth of research on the flow boiling heat transfer characteristics of mixed working fluids suitable for ORC, which seriously hinders the development of accurate designs for ORC heat exchangers. Therefore, more attention should be paid to studies of heat transfer characteristics in the context of the ORC in the future.

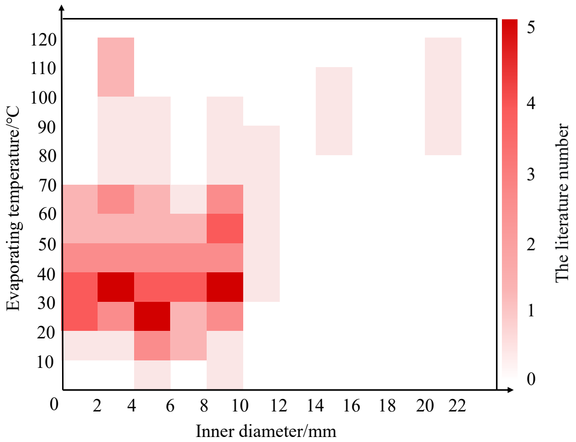


Figure 21. Distribution of experimental conditions of the flow boiling heat transfer characteristics of the ORC-recommended working fluid.

5.3. Simultaneous Optimization of Heat Exchanger and ORC System

Heat exchanger optimization is a critical link in the enhancement of thermodynamic and economic performance of the ORC system. Generally, the optimization of heat exchangers can be classified into two kinds: structural optimization, and topology optimization. Among them, the development of structural optimization for the heat exchanger in the ORC system has received much focus in recent years. In practice, remarkable performance improvement can be achieved by carefully selecting the initial structures and optimization criteria. Currently, the research on optimizing ORC heat exchangers mainly focuses on the plate, shell-and-tube, and fin-and-tube heat exchangers.

Table 4 lists some heat exchanger optimization methods and models for ORC systems. Some of them only focused on heat exchanger performance [56,104,105]. Due to the strong correlation between the heat exchanger and the ORC system, it is recommended that the operating parameters and heat exchanger geometry are optimized jointly to guarantee that the configuration of the heat exchangers is optimal for ORC performance. Realistic heat exchanger models, describing the heat transfer performance of the heat exchangers according to geometric parameters, are required to carry out such a system optimization. As shown in Table 4, some researchers dealt with single objective functions while ignoring the development of other objectives. In most single objective optimization studies, specific investment cost is a common choice because it reflects the application and investment potential of the ORC system. The specific investment cost is related to the heat exchanger type, raw material, and manufacturing process. On the other hand, other researchers adopted the weighted sum or the true multi-objective optimization to intensify the heat transfer and improving the thermo-economic performance concurrently of the ORC system. As mentioned above, the cost reduction is in conflict with the performance improvement. The multi-objective optimization is applied to deal with the contradictory relationship between the thermodynamic and economic target and to provide investors with a trade-off solution. For the optimization, the optimization variables need to be selected according to the specific heat exchanger type and optimization targets. For example, the optimization variables of a plate heat exchanger consist primarily of plate width, plate length, and plate spacing due to their strong correlation with *HTC* and pressure drop [104,105]. The optimization variables of shell-and-tube heat exchangers are usually tube diameter, shell diameter, tube pitch, and baffle spacing [33,106], while the tube-and-fin heat exchangers includes tube length, tube diameter, fin thickness, and fin length, etc. [73,74,107,108].

An optimization algorithm with high precision and fast solutions is required for the optimization. In rigorous modeling and optimization of a heat exchanger, the optimization variables consist of geometrical and structural parameters at given heat load and operating parameters. However, the optimization problem is challenging to resolve because of the thermophysical properties coupled with the geometry structural parameters. Particle swarm [109], gradient-based optimization method [110], and genetic algorithms [111] are the common stochastic optimization tools for heat exchanger optimization in the ORC system, while the NSGA-II [112] is suitable to address the multi-optimization problem. These stochastic algorithms are direct and random search methods that explicitly use multiple solutions in each iteration. Even though single -objective optimization and multi-objective optimization are entirely distinct concepts, the optimization logic of stochastic algorithms for ORC systems and heat exchanger is similar. Walraven et al. [106] introduced the logic of performing an iteration between the optimization of the system level and the component level using a stochastic algorithm. The ORC system level was optimized firstly using pinch analysis, pursuing an optimal value of the pressure drop and the pinch point temperature differences. Then the heat transfer area of each heat exchanger was minimized separately based on the heat load from system level. At last, the optimal result could be obtained after iterating the optimization between the system level and the component level. The optimization method introduced by Walraven et al. [106] is a common method used in the studies of heat exchanger optimization [33,39,55,68,73,74,107,108,113,114], while the optimal parameters of the system level or component level should be chosen with care according to the objective functions. Obviously, there are many studies that only optimize at the system level [59,115] or component level [104,105].

The iteration between the optimization of the system level and component level, which requires extensive calculation time, is a necessary step to avoid a locally optimal solution when using a stochastic algorithm in the optimization process. However, when the variables and constraint equations are many or when the design problems involve a couple of interactions between multiple disciplines, it is typically challenging to find a feasible solution using a stochastic algorithm [116]. Mathematical programming and deterministic algorithms have distinct advantages to solve problems with several continuous variables, discrete variables, and constraint conditions. Luo et al. [73,114] and Yi et al. [74] formulated a mixed integer non-linear programming (MINLP) model and developed a solution strategy for LSC design optimization involving multiple continuous and discrete variables. The formulated MINLP optimization model is non-convex. A sequential optimization algorithm using CONOPT, MINOS, and SNOPT was proposed to solve the relaxation model of the original MINLP model, avoiding solutions prematurely stuck in the local minimum. Then, an effective local MINLP solver was applied to obtain a local solution for the original MINLP model. Finally, a global solver was used to search for a global solution based on the local solution achieved by using the local MINLP solver. It should be emphasized that this method was suitable for solving single-objective optimization problems. Yi et al. [70] developed a two-step solution algorithm to solve the multi-objective problem. First, two single-objective optimization problems were solved separately to obtain the bounds for the two objectives by using the solution strategy developed in Luo et al. [73,114] and Yi et al. [74]. Then, an ε-constrained method [117] was adopted to conduct the multi-objective optimization.

Overall, this sub-section introduces the major optimization methods for the heat exchangers in the context of ORC. The critical factors of heat exchanger optimization work, such as optimization variables, objective functions, optimization algorithms, and solution strategies, are generally summarized. Most optimization frameworks presented in the current literature, which are shown in Table 4, can achieve the thermally, environmentally, and economically optimal design of the ORC system and heat exchangers in a reasonable amount of time. However, due to the complex interactions between multiple variables, there is no almighty optimization method suitable for all optimization scenarios to simultaneously achieve fast, accurate, and precise optimal results. Apparently, future efforts will be needed to optimize the heat exchanger, particularly to implement appropriate parametrization schemes and develop optimizers capable of handling multiple objectives, integrating the various constraints and predicting more complex system–component problems.

Table 4. Summary and comparison of the heat exchanger optimization in ORC.

Ref.	Type	Algorithm	Objectives	Variables
[104]	Plate condenser	NSGA-II	The total heat transfer surface area and pressure drop	Length, width and plate spacing
[105]	Plate evaporator	NSGA-II	Minimum cost of evaporator and minimum pressure drop	Length, width and plate spacing
[56]	Shell-and-tube evaporator with	Particle swarm	Volume fraction of the vapor at the tube outlet	Angular frequency and oscillating velocity amplitude
[59]	Shell and louvered fin mini-tubes heat exchanger	-	Maximize the system efficiency	Heat transfer load, mass flow rate, evaporation and condensation pressure
[33]	Shell-and-tube heat exchangers	-	Minimize specific investment cost	Pinch point temperature differences in the evaporator and condenser, evaporation pressure, turbine inlet temperature
[106]	Shell-and-tube heat exchangers	Gradient-based optimization method	Maximize the system efficiency	Tube outside diameter, relative tube pitch, relative baffle cut, baffle spacing, shell diameter, ratio of tube diameter to shell diameter
[36]	Plate heat exchangers and shell-and-tube heat exchangers	Gradient-based optimization method	Maximize the system efficiency	Corrugation amplitude, width, angle, channels, ratio of corrugation width to corrugation amplitude; shell diameter, tube outside diameter, relative tube pitch, relative baffle cut, baffle spacing, ratio of tube diameter to shell diameter
[115]	Fin-and-tube evaporator	NSGA-II	Net power output per unit heat transfer area and exergy destruction rate	Evaporation pressure, superheat degree and condensation temperature
[108]	Fin-and-tube evaporator	Particle swarm	Volume of tube bundle, exhaust pressure drop, and total annual cost	Inlet radius, fin height, fin thickness and fin spacing. Operating pressure and temperature of the ORC system
[55]	Fin-and-tube evaporator	Genetic algorithms	Influence of the evaporator on the operation of the diesel engine	Ellipticity ratio of the tube in the evaporator and tooth depth of the star-shaped fin
[39]	Shell-and-tube heat exchangers and plate heat exchangers	Genetic algorithms	Maximum exergy efficiency, minimum specific cost and minimum heat exchanger area per unit power output	The outer diameters of the tubes, the tube length, the outside diameter of the shell, pitch between the tube centers, and the baffle spacing; The plate length, plate width, plate thickness, chevron angle, and channel spacing
[107]	Fin-and-tube condenser with liquid-separated condensation	CONOPT, MINOS, and SNOPT	Minimize the total annual cost	Continuous variables (e.g., tube length, tube diameter, fin length, fin thickness), discrete variables (e.g., tube number per pass, tube pass number, fin number per length, total tube number)
[73]	Fin-and-tube condenser with liquid-separated condensation	CONOPT, MINOS, and SNOPT	Minimize the total annual cost	Tube diameter and tube length, the selection of integer variables (e.g., total tube number, number of passes of LSC, tube number per pass, and fin number per unit tube length), and correlation coefficients

6. Prospects

In the light of the above systematic review of the existing research, Figure 22 summarizes research aspects that require further development.

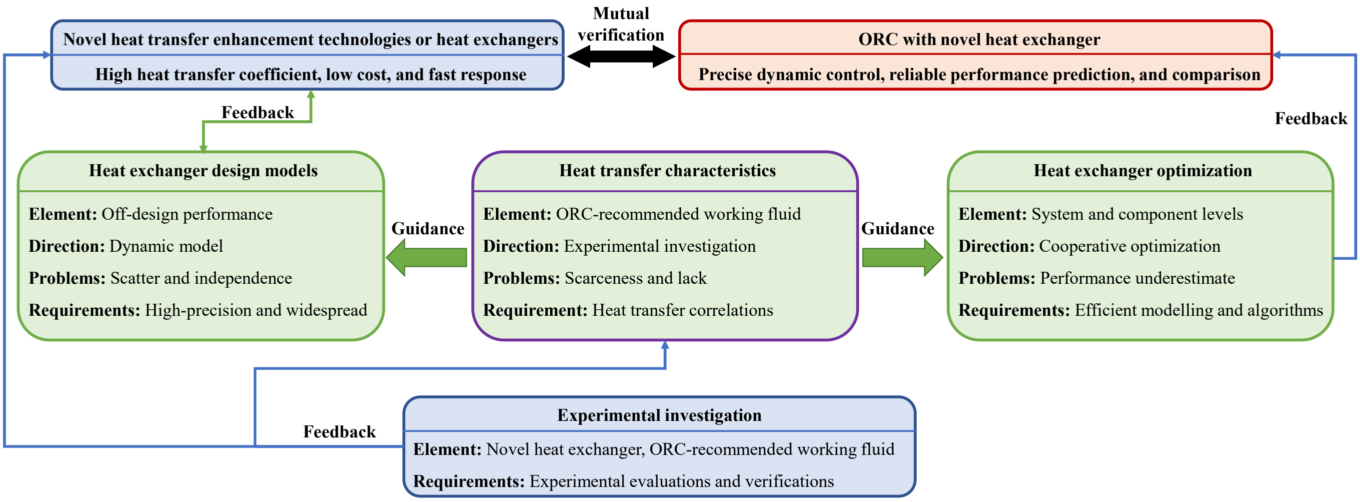


Figure 22. Future research directions of ORC with heat transfer enhancement technologies.

Novel heat transfer enhancement technologies or heat exchangers with high heat transfer coefficient, low cost, and fast response used in the ORC are gaining in popularity. The ORC system usually operates under off-design working conditions on account of the frequent variations of heat source/sink parameters. Although conventional heat exchangers have strong adaptability in ORC systems, they still have shortcomings and are not completely favorable for the ORC. New forms of heat exchangers, including material innovations and structural creations, will effectively promote the popularization of the ORC system. The afore-mentioned literature involves multiple research projects of design modelling, experimental study, operating optimization, and economic verification. Similarly, the application of a novel heat exchanger in the ORC is bound to affect the ORC system structure, leading the ORC system to perform with new operating characteristics. The specific novel heat exchangers should be custom-made for different configurations of the ORC system [118]. Precise dynamic control, reliable performance prediction, and performance comparison of the new ORC configuration with a novel heat exchanger should be further developed after proposing a novel heat exchanger to ensure that the system operates with high efficiency, flexibility, and stability.

High-precision and general heat exchanger design models will provide positive assistance for the widespread application of the ORC. The economic performance, dynamic responses, and the off-design performance of the heat exchanger need to be considered during the design process simultaneously. Dynamic models reflecting off-design operating characteristics are particularly required. The prediction accuracy of general dynamic models needs to be improved. However, dynamic heat exchanger design usually depends on commercial software, driving up the design cost. The application scenarios of the ORC are complex because of the different characteristics of heat sources or sinks, which leaves the existing design models scattered and independent. More attention should be paid to the investigation of high-precision and widespread heat exchanger design models according to the features of the ORC.

It is urgent to conduct investigations on the heat transfer characteristics for ORC-recommended working fluids. The research on heat transfer characteristics in the ORC is the foundation for enhancing the heat exchanger and system performance. Zeotropic mixtures have become a new trend for performance enhancement in ORC. The zeotropic mixtures have the potential to improve ORC performance, but their application is limited by poor heat transfer characteristics. However, there is little research on the flow boiling heat transfer characteristics of the zeotropic mixtures suitable for ORC. Even for traditional pure fluids, the lack of heat transfer correlations between large pipe diameters and high evaporating temperatures restrains the accurate design of heat exchangers and practical applications of the ORC. It is necessary to conduct investigations on heat transfer characteristics for ORC systems for different working fluids, evaporation or condensation temperatures, and geometric parameters.

Cooperative optimization of system and heat exchanger levels should be carried out during the design process to guarantee optimal life-span performance. Heat exchanger optimization is a critical aspect in the enhancement of thermo-economic performance of the ORC system because of the strong relevance of the optimization variables between the system level and heat exchanger level. The system level consists of operating parameters, working fluid types, and system configurations, while the heat exchanger level comprises the materials, types, and structural parameters. The independent optimization of the heat exchanger is easy to underestimate with regard to the ultimate performance of the ORC. Multi-objective optimization is attracting more and more attention due to the competitive relationship between thermodynamic performance, environmental performance, and economic performance. The trade-off solution that strikes a balance between energy, economy, and environment is more in line with application and development of the ORC system under carbon neutral policies. In addition, collaborative optimization of heat exchange topology and system parameters is also a performance enhancement measure that deserves further study [119]. Future work is necessary to optimize the heat exchanger, particularly to implement suitable parametrization schemes and develop optimizers capable of handling multiple objectives, integrating the various constraints and predicting more complex system–component problems.

Experimental investigations on the ORC with novel heat transfer enhancement technologies or heat exchangers needs to be implemented. Previous studies on t novel heat exchangers have concentrated on theoretical analysis, while the influences of system parameters on the practical thermodynamic properties and heat transfer enhancement remain as yet uncertain for novel heat exchangers. Experimental evaluations and verifications for heat transfer enhancement and off-design operation characteristics of the ORC with novel heat transfer enhanced technologies or heat exchangers are urgently needed.

7. Conclusions

This study conducted a systematic review of the literature on ORC system performance improvements related to design and optimization based on heat transfer enhancement technologies or novel heat exchangers. The developments and current challenges were summarized, and future research trends were identified.

The literature review on heat exchanger screening in the ORC revealed that there is no unique type of heat exchanger that yields optimal performance for all configurations of ORCs. Conducting type screening and structural optimization for heat exchangers in specific configurations or operation conditions of the ORC is an ongoing topic. Improving the structure of heat exchangers and cycles can achieve more desirable performance enhancement for different types of ORCs. Innovations in new material applications and structures are promising heat transfer enhancement technologies for the heat exchangers in ORCs. Micro-channel and liquid–vapor separation have shown superior performance in ORC systems with different configurations. New material applications in the heat exchanger is a viable solution to reduce the investment cost and impact on the environment, though it is rarely reported. Constructive suggestions regarding the development of novel heat exchangers and their ORC systems were proposed in this study.

Dynamic models are imperative for reflecting the off-design performance of heat exchanger and the life-span operation performance of the ORC. Developing an accurate and general dynamic model for the heat exchanger as well as the ORC system is urgently necessary for widespread application of the ORC. Studies have been widely conducted with a single-minded focus on component level or system level of the optimization. Cooperative optimization of system and heat exchanger levels has not yet been fully explored due to their complex coupling interactions. Future solutions were also proposed in this review for addressing the current difficulties. As an accurate heat exchanger model is heavily dependent on the heat transfer correlations of heat transfer fluid, the experimental studies on heat transfer characteristic around suitable working conditions of ORC were reviewed. The prospects of high precision and widespread heat transfer corrections were highlighted.

Author Contributions: Conceptualization, X.L.; methodology, P.L., Z.L. and X.L.; investigation, Y.X., J.W., K.C., Y.L., J.C., Z.Y. and J.H.; writing—original draft preparation, P.L., Z.L. and Y.X.; writing—review and editing, P.L., Z.L., X.L. and Y.X.; visualization, P.L., Z.L. and Y.X.; supervision, X.L. and Y.C.; project administration, X.L. and Y.C.; funding acquisition, X.L. and Y.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 51876043 and the State Key Program of National Natural Science Foundation of China, grant number 51736005.

Data Availability Statement: Not applicable.

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

References

1. Cui, Y.; Zhao, H. Marine renewable energy project: The environmental implication and sustainable technology. *Ocean Coast. Manag.* **2023**, *232*, 106415. [CrossRef]
2. Anika, O.C.; Nnabuife, S.G.; Bello, A.; Okoroafor, E.R.; Kuang, B.; Villa, R. Prospects of low and zero-carbon renewable fuels in 1.5-degree net zero emission actualisation by 2050: A critical review. *Carbon Capture Sci. Technol.* **2022**, *5*, 100072. [CrossRef]
3. Farhat, O.; Faraj, J.; Hachem, F.; Castelain, C.; Khaled, M. A recent review on waste heat recovery methodologies and applications: Comprehensive review, critical analysis and potential recommendations. *Clean. Eng. Technol.* **2022**, *6*, 100387. [CrossRef]
4. Peris, B.; Navarro-Esbrí, J.; Molés, F.; Mota-Babiloni, A. Experimental study of an ORC (organic Rankine cycle) for low grade waste heat recovery in a ceramic industry. *Energy* **2015**, *85*, 534–542. [CrossRef]
5. Patil, V.R.; Biradar, V.I.; Shreyas, R.; Garg, P.; Orosz, M.S.; Thirumalai, N. Techno-economic comparison of solar organic Rankine cycle (ORC) and photovoltaic (PV) systems with energy storage. *Renew. Energy* **2017**, *113*, 1250–1260. [CrossRef]
6. Wang, M.; Jing, R.; Zhang, H.; Meng, C.; Li, N.; Zhao, Y. An innovative Organic Rankine Cycle (ORC) based Ocean Thermal Energy Conversion (OTEC) system with performance simulation and multi-objective optimization. *Appl. Therm. Eng.* **2018**, *145*, 743–754. [CrossRef]
7. DiPippo, R. Geothermal power plants: Evolution and performance assessments. *Geothermics* **2015**, *53*, 291–307. [CrossRef]
8. Qiu, G.; Shao, Y.; Li, J.; Liu, H.; Riffat, S. Experimental investigation of a biomass-fired ORC-based micro-CHP for domestic applications. *Fuel* **2012**, *96*, 374–382. [CrossRef]
9. Quoilin, S.; Broek, M.V.D.; Declaye, S.; Dewallef, P.; Lemort, V. Techno-economic survey of Organic Rankine Cycle (ORC) systems. *Renew. Sustain. Energy Rev.* **2013**, *22*, 168–186. [CrossRef]
10. History of ORC. Knowledge Center for Organic Rankine Cycle. Available online: http://www.kcorc.org/en/science-technology/history/ (accessed on 7 November 2022).
11. Tartière, T.; Astolfi, M. A World Overview of the Organic Rankine Cycle Market. *Energy Procedia* **2017**, *129*, 2–9. [CrossRef]
12. Tocci, L.; Pal, T.; Pesmazoglou, I.; Franchetti, B. Small Scale Organic Rankine Cycle (ORC): A Techno-Economic Review. *Energies* **2017**, *10*, 413. [CrossRef]
13. Lecompte, S.; Huisseune, H.; Van Den Broek, M.; Vanslambrouck, B.; De Paepe, M. Review of organic Rankine cycle (ORC) architectures for waste heat recovery. *Renew. Sustain. Energy Rev.* **2015**, *47*, 448–461. [CrossRef]
14. Kumar, A.; Rakshit, D. A critical review on waste heat recovery utilization with special focus on Organic Rankine Cycle applications. *Clean. Eng. Technol.* **2021**, *5*, 100292. [CrossRef]
15. Chen, Q.; Xu, J.; Chen, H. A new design method for Organic Rankine Cycles with constraint of inlet and outlet heat carrier fluid temperatures coupling with the heat source. *Appl. Energy* **2012**, *98*, 562–573. [CrossRef]
16. Chen, J.; Zheng, X.; Guo, G.; Luo, X.; Chen, Y.; Yang, Z. A flexible and multi-functional organic Rankine cycle system: Preliminary experimental study and advanced exergy analysis. *Energy Convers. Manag.* **2019**, *187*, 339–355. [CrossRef]
17. Walraven, D.; Laenen, B.; D'Haeseleer, W. Economic system optimization of air-cooled organic Rankine cycles powered by low-temperature geothermal heat sources. *Energy* **2015**, *80*, 104–113. [CrossRef]
18. Fawaz, A.; Hua, Y.; Le Corre, S.; Fan, Y.; Luo, L. Topology optimization of heat exchangers: A review. *Energy* **2022**, *252*, 124053. [CrossRef]
19. Ajarostaghi, S.S.M.; Zaboli, M.; Javadi, H.; Badenes, B.; Urchueguia, J.F. A Review of Recent Passive Heat Transfer Enhancement Methods. *Energies* **2022**, *15*, 986. [CrossRef]
20. Shanker, G.R.; Homan, K. Convective transport from geothermal borehole heat exchangers embedded in a fluid-saturated porous medium. *Renew. Energy* **2022**, *196*, 328–342. [CrossRef]

21. Spizzichino, M.; Sinibaldi, G.; Romano, G. Experimental investigation on fluid mechanics of micro-channel heat transfer devices. *Exp. Therm. Fluid Sci.* **2020**, *118*, 110141. [CrossRef]
22. Kaur, I.; Singh, P. State-of-the-art in heat exchanger additive manufacturing. *Int. J. Heat Mass Transf.* **2021**, *178*, 121600. [CrossRef]
23. Hussein, H.A.M.; Zulkifli, R.; Mahmood, W.M.F.B.W.; Ajeel, R.K. Structure parameters and designs and their impact on performance of different heat exchangers: A review. *Renew. Sustain. Energy Rev.* **2022**, *154*, 111842. [CrossRef]
24. Zhar, R.; Allouhi, A.; Jamil, A.; Lahrech, K. A comparative study and sensitivity analysis of different ORC configurations for waste heat recovery. *Case Stud. Therm. Eng.* **2021**, *28*, 101608. [CrossRef]
25. Lu, P.; Luo, X.; Wang, J.; Chen, J.; Liang, Y.; Yang, Z.; He, J.; Wang, C.; Chen, Y. Thermodynamic analysis and evaluation of a novel composition adjustable Carnot battery under variable operating scenarios. *Energy Convers. Manag.* **2022**, *269*, 116117. [CrossRef]
26. Zhao, Y.; Liu, G.; Li, L.; Yang, Q.; Tang, B.; Liu, Y. Expansion devices for organic Rankine cycle (ORC) using in low temperature heat recovery: A review. *Energy Convers. Manag.* **2019**, *199*, 111944. [CrossRef]
27. Alshammari, F.; Karvountzis-Kontakiotis, A.; Pesyridis, A.; Usman, M. Expander Technologies for Automotive Engine Organic Rankine Cycle Applications. *Energies* **2018**, *11*, 1905. [CrossRef]
28. Zhang, C.; Liu, C.; Wang, S.; Xu, X.; Li, Q. Thermo-economic comparison of subcritical organic Rankine cycle based on different heat exchanger configurations. *Energy* **2017**, *123*, 728–741. [CrossRef]
29. Arsenyeva, O.P.; Tovazhnyansky, L.L.; Kapustenko, P.O.; Khavin, G.L. Optimal design of plate-and-frame heat exchangers for efficient heat recovery in process industries. *Energy* **2011**, *36*, 4588–4598. [CrossRef]
30. Luo, J.; Lu, P.; Chen, K.; Luo, X.; Chen, J.; Liang, Y.; Yang, Z.; Chen, Y. Experimental and simulation investigation on the heat exchangers in an ORC under various heat source/sink conditions. *Energy* **2023**, *264*, 126189. [CrossRef]
31. Chen, L.-Y.; Adi, V.S.K.; Laxmidewi, R. Shell and tube heat exchanger flexible design strategy for process operability. *Case Stud. Therm. Eng.* **2022**, *37*, 102163. [CrossRef]
32. Caputo, A.C.; Federici, A.; Pelagagge, P.M.; Salini, P. On the design of shell-and-tube heat exchangers under uncertain operating conditions. *Appl. Therm. Eng.* **2022**, *212*, 118541. [CrossRef]
33. Li, J.; Yang, Z.; Hu, S.; Yang, F.; Duan, Y. Effects of shell-and-tube heat exchanger arranged forms on the thermo-economic performance of organic Rankine cycle systems using hydrocarbons. *Energy Convers. Manag.* **2019**, *203*, 112248. [CrossRef]
34. Banu, P.A.; Dhanapal, B.; Pillai, T.M.; Chellappa, B.; Sathyamurthy, R. Thermodynamic and hydraulic design characteristics of the fin tube heat exchanger. *Mater. Today Proc.* **2022**, *62*, 2380–2387. [CrossRef]
35. Tahseen, T.A.; Ishak, M.; Rahman, M. An overview on thermal and fluid flow characteristics in a plain plate finned and un-finned tube banks heat exchanger. *Renew. Sustain. Energy Rev.* **2015**, *43*, 363–380. [CrossRef]
36. Walraven, D.; Laenen, B.; D'Haeseleer, W. Comparison of shell-and-tube with plate heat exchangers for the use in low-temperature organic Rankine cycles. *Energy Convers. Manag.* **2014**, *87*, 227–237. [CrossRef]
37. Lee, Y.-R.; Kuo, C.-R.; Liu, C.-H.; Fu, B.-R.; Wang, C.-C. Response of a 50kW Organic Rankine Cycle System Subject to Influence of Evaporators. *Energy Procedia* **2014**, *61*, 635–638. [CrossRef]
38. Bull, J.; Buick, J.M.; Radulovic, J. Heat Exchanger Sizing for Organic Rankine Cycle. *Energies* **2020**, *13*, 3615. [CrossRef]
39. Xu, J.; Luo, X.; Chen, Y.; Mo, S. Multi-criteria Design Optimization and Screening of Heat Exchangers for a Subcritical ORC. *Energy Procedia* **2015**, *75*, 1639–1645. [CrossRef]
40. Jiménez-Arreola, M.; Wieland, C.; Romagnoli, A. Dynamic response comparison of direct and indirect evaporation options in ORC systems for waste heat recovery. *Energy Procedia* **2019**, *158*, 1606–1612. [CrossRef]
41. Jiménez-Arreola, M.; Wieland, C.; Romagnoli, A. Direct vs indirect evaporation in Organic Rankine Cycle (ORC) systems: A comparison of the dynamic behavior for waste heat recovery of engine exhaust. *Appl. Energy* **2019**, *242*, 439–452. [CrossRef]
42. Chatzopoulou, M.A.; Lecompte, S.; De Paepe, M.; Markides, C.N. Off-design optimisation of organic Rankine cycle (ORC) engines with different heat exchangers and volumetric expanders in waste heat recovery applications. *Appl. Energy* **2019**, *253*, 113442. [CrossRef]
43. Chatzopoulou, M.A.; Lecompte, S.; De Paepe, M.; Markides, C.N. Off-design operation of ORC engines with different heat exchanger architectures in waste heat recovery applications. *Energy Procedia* **2019**, *158*, 2348–2353. [CrossRef]
44. Rohmah, N.; Pikra, G.; Purwanto, A.J.; Pramana, R.I. The Effect of Plate Spacing in Plate Heat Exchanger Design as a Condenser in Organic Rankine cycle for Low Temperature Heat Source. *Energy Procedia* **2015**, *68*, 87–96. [CrossRef]
45. Ravi, R.; Pachamuthu, S. Design and Development of Innovative Protracted-Finned Counter Flow Heat Exchanger (PFCHE) for an Engine WHR and Its Impact on Exhaust Emissions. *Energies* **2018**, *11*, 2717. [CrossRef]
46. Luo, X.; Yi, Z.; Chen, Z.; Chen, Y.; Mo, S. Performance comparison of the liquid–vapor separation, parallel flow, and serpentine condensers in the organic Rankine cycle. *Appl. Therm. Eng.* **2016**, *94*, 435–448. [CrossRef]
47. Zhang, Y.-F.; Li, M.-J.; Ren, X.; Duan, X.-Y.; Wu, C.-J.; Xi, H.; Feng, Y.-Q.; Gong, L.; Hung, T.-C. Effect of heat source supplies on system behaviors of ORCs with different capacities: An experimental comparison between the 3 kW and 10 kW unit. *Energy* **2022**, *254*, 124267. [CrossRef]
48. Zheng, X.; Luo, X.; Luo, J.; Chen, J.; Liang, Y.; Yang, Z.; Chen, Y.; Wang, H. Experimental investigation of operation behavior of plate heat exchangers and their influences on organic Rankine cycle performance. *Energy Convers. Manag.* **2020**, *207*, 112528. [CrossRef]
49. Venegas, T.; Qu, M.; Nawaz, K.; Wang, L. Critical review and future prospects for desiccant coated heat exchangers: Materials, design, and manufacturing. *Renew. Sustain. Energy Rev.* **2021**, *151*, 111531. [CrossRef]

50. Khail, A.A.; Erişen, A. Heat transfer and performance enhancement investigation of novel plate heat exchanger. *Therm. Sci. Eng. Prog.* **2022**, *34*, 101368. [CrossRef]
51. Aláez, S.G.; Bombarda, P.; Invernizzi, C.; Iora, P.; Silva, P. Evaluation of ORC modules performance adopting commercial plastic heat exchangers. *Appl. Energy* **2015**, *154*, 882–890. [CrossRef]
52. Kim, D.Y.; Kim, K.C. Thermal performance of brazed metalfoam-plate heat exchanger as an evaporator for organic Rankine cycle. *Energy Procedia* **2017**, *129*, 451–458. [CrossRef]
53. Nematollahi, O.; Abadi, G.B.; Kim, D.Y.; Kim, K.C. Experimental study of the effect of brazed compact metal-foam evaporator in an organic Rankine cycle performance: Toward a compact ORC. *Energy Convers. Manag.* **2018**, *173*, 37–45. [CrossRef]
54. Cao, S.; Xu, J.; Li, Y.; Yan, Y. Condensation heat transfer of R245fa in a shell-tube heat exchanger at slightly inclined angles. *Int. J. Therm. Sci.* **2017**, *115*, 197–209. [CrossRef]
55. Zhang, W.; Yang, F.; Zhang, H.; Ping, X.; Yan, D. Numerical analysis and optimization design of fin-and-tube evaporator in organic Rankine cycle system for diesel engine waste heat recovery. *Int. J. Heat Mass Transf.* **2021**, *175*, 121376. [CrossRef]
56. Zhang, W.; Yang, F.; Zhang, H.; Ping, X.; Yan, D.; Wang, C. Application of two-phase pulsating flow in organic Rankine cycle system for diesel engine waste heat recovery. *Energy* **2021**, *243*, 122776. [CrossRef]
57. Wang, D.; Lu, H.; Li, L.; Fu, S.; Dai, X.; Shi, L. Comprehensive comparison of the applicability of internally ribbed and microfin tubes for TORC systems. *Int. J. Heat Mass Transf.* **2022**, *186*, 122470. [CrossRef]
58. Nguyen, D.H.; Ahn, H.S. A comprehensive review on micro/nanoscale surface modification techniques for heat transfer enhancement in heat exchanger. *Int. J. Heat Mass Transf.* **2021**, *178*, 121601. [CrossRef]
59. Mastrullo, R.; Mauro, A.W.; Revellin, R.; Viscito, L. Modeling and optimization of a shell and louvered fin mini-tubes heat exchanger in an ORC powered by an internal combustion engine. *Energy Convers. Manag.* **2015**, *101*, 697–712. [CrossRef]
60. Chen, J.; Zhu, K.; Luo, X.; Chen, Y.; Yang, Z. Application of liquid-separation condensation to plate heat exchanger: Comparative studies. *Appl. Therm. Eng.* **2019**, *157*, 113739. [CrossRef]
61. Li, Y.; Luo, X.; Wang, Z.; Yang, Z.; Chen, J.; Liang, Y.; Wang, C.; Chen, Y. Numerical simulation on the header-orifice structure-based liquid-vapor separator used in liquid-separation condenser. *Chem. Eng. Sci.* **2021**, *235*, 116475. [CrossRef]
62. Chen, J.; Li, Y.; Ding, R.; Lin, X.; Chen, Y.; Luo, X.; Yang, Z. Comparative performance of air-conditioning systems with different refrigerant circuitries in liquid-separation condenser. *Int. J. Refrig.* **2018**, *92*, 154–164. [CrossRef]
63. Chen, J.; Ding, R.; Li, Y.; Lin, X.; Chen, Y.; Luo, X.; Yang, Z. Application of a vapor–liquid separation heat exchanger to the air conditioning system at cooling and heating modes. *Int. J. Refrig.* **2018**, *100*, 27–36. [CrossRef]
64. Huang, K.; Li, J.; Chen, J.; Chen, Y.; Luo, X.; Liang, Y.; He, J.; Yang, Z. Explorations of multi-pass-orifice header in the liquid-separation condenser by using CFD simulation. *Int. J. Heat Mass Tran.* **2023**, *200*, 123482. [CrossRef]
65. Li, J.; Liu, Q.; Duan, Y.; Yang, Z. Performance analysis of organic Rankine cycles using R600/R601a mixtures with liquid-separated condensation. *Appl. Energy* **2017**, *190*, 376–389. [CrossRef]
66. Li, J.; Hu, S.; Yang, F.; Duan, Y.; Yang, Z. Thermo-economic performance evaluation of emerging liquid-separated condensation method in single-pressure and dual-pressure evaporation organic Rankine cycle systems. *Appl. Energy* **2019**, *256*, 113974. [CrossRef]
67. Li, J.; Yang, Z.; Hu, S.; Yang, F.; Duan, Y. Thermo-economic performance improvement of butane/isopentane mixtures in organic Rankine cycles by liquid-separated condensation method. *Appl. Therm. Eng.* **2020**, *181*, 115941. [CrossRef]
68. Luo, X.; Liang, Z.; Guo, G.; Wang, C.; Chen, Y.; Ponce-Ortega, J.M.; El-Halwagi, M.M. Thermo-economic analysis and optimization of a zoetropic fluid organic Rankine cycle with liquid-vapor separation during condensation. *Energy Convers. Manag.* **2017**, *148*, 517–532. [CrossRef]
69. Lu, P.; Luo, X.; Wang, J.; Chen, J.; Liang, Y.; Yang, Z.; Wang, C.; Chen, Y. Thermo-economic design, optimization, and evaluation of a novel zeotropic ORC with mixture composition adjustment during operation. *Energy Convers. Manag.* **2021**, *230*, 113771. [CrossRef]
70. Yi, Z.; Luo, X.; Yang, Z.; Wang, C.; Chen, J.; Chen, Y.; Ponce-Ortega, J.M. Thermo-economic-environmental optimization of a liquid separation condensation-based organic Rankine cycle driven by waste heat. *J. Clean. Prod.* **2018**, *184*, 198–210. [CrossRef]
71. Xu, B.; Rathod, D.; Yebi, A.; Filipi, Z.; Onori, S.; Hoffman, M. A comprehensive review of organic rankine cycle waste heat recovery systems in heavy-duty diesel engine applications. *Renew. Sustain. Energy Rev.* **2019**, *107*, 145–170. [CrossRef]
72. Qureshi, I.A.; Waqas, A.; Ali, M.; Mehmood, A.; Javed, A. Performance evaluation of ORC system using evacuated flat plate Photovoltaic-Thermal collector as an evaporator. *Sol. Energy* **2021**, *230*, 859–873. [CrossRef]
73. Luo, X.; Yi, Z.; Zhang, B.; Mo, S.; Wang, C.; Song, M.; Chen, Y. Mathematical modelling and optimization of the liquid separation condenser used in organic Rankine cycle. *Appl. Energy* **2017**, *185*, 1309–1323. [CrossRef]
74. Yi, Z.; Luo, X.; Chen, J.; Chen, Y. Mathematical modelling and optimization of a liquid separation condenser-based organic Rankine cycle used in waste heat utilization. *Energy* **2017**, *139*, 916–934. [CrossRef]
75. Luo, X.; Huang, R.; Yang, Z.; Chen, J.; Chen, Y. Performance investigation of a novel zeotropic organic Rankine cycle coupling liquid separation condensation and multi-pressure evaporation. *Energy Convers. Manag.* **2018**, *161*, 112–127. [CrossRef]
76. Hu, S.; Li, J.; Yang, F.; Yang, Z.; Duan, Y. Thermodynamic analysis of serial dual-pressure organic Rankine cycle under off-design conditions. *Energy Convers. Manag.* **2020**, *213*, 112837. [CrossRef]

77. Liang, Z.; Liang, Y.; Luo, X.; Chen, J.; Yang, Z.; Wang, C.; Chen, Y. Synthesis and simultaneous optimization of multi-heat source multi-pressure evaporation organic Rankine cycle with mixed working fluid. *Energy Convers. Manag.* **2021**, *251*, 114930. [CrossRef]
78. Zhang, J.; Zhang, X.; Zhang, Z.; Zhou, P.; Zhang, Y.; Yuan, H. Performance improvement of ocean thermal energy conversion organic Rankine cycle under temperature glide effect. *Energy* **2022**, *246*, 123440. [CrossRef]
79. Li, D.; He, Z.; Wang, Q.; Wang, X.; Wu, W.; Xing, Z. Thermodynamic analysis and optimization of a partial evaporating dual-pressure organic rankine cycle system for low-grade heat recovery. *Appl. Therm. Eng.* **2020**, *185*, 116363. [CrossRef]
80. Surendran, A.; Seshadri, S. Design and performance analysis of a novel Transcritical Regenerative Series Two stage Organic Rankine Cycle for dual source waste heat recovery. *Energy* **2020**, *203*, 117800. [CrossRef]
81. Yu, W.; Xu, Y.; Wang, H.; Ge, Z.; Wang, J.; Zhu, D.; Xia, Y. Thermodynamic and thermoeconomic performance analyses and optimization of a novel power and cooling cogeneration system fueled by low-grade waste heat. *Appl. Therm. Eng.* **2020**, *179*, 115667. [CrossRef]
82. Surendran, A.; Seshadri, S. An ejector based Transcritical Regenerative Series Two-Stage Organic Rankine Cycle for dual/multi-source heat recovery applications. *Therm. Sci. Eng. Prog.* **2021**, *27*, 101158. [CrossRef]
83. Meng, N.; Li, T.; Gao, X.; Liu, Q.; Li, X.; Gao, H. Thermodynamic and techno-economic performance comparison of two-stage series organic Rankine cycle and organic Rankine flash cycle for geothermal power generation from hot dry rock. *Appl. Therm. Eng.* **2021**, *200*, 117715. [CrossRef]
84. Huang, Y.; Chen, J.; Chen, Y.; Luo, X.; Liang, Y.; He, J.; Yang, Z. Performance explorations of an organic Rankine cycle featured with separating and mixing composition of zeotropic mixture. *Energy* **2022**, *257*, 124535. [CrossRef]
85. Jiménez-Arreola, M.; Pili, R.; Wieland, C.; Romagnoli, A. Analysis and comparison of dynamic behavior of heat exchangers for direct evaporation in ORC waste heat recovery applications from fluctuating sources. *Appl. Energy* **2018**, *216*, 724–740. [CrossRef]
86. Karellas, S.; Schuster, A.; Leontaritis, A.-D. Influence of supercritical ORC parameters on plate heat exchanger design. *Appl. Therm. Eng.* **2012**, *33–34*, 70–76. [CrossRef]
87. Wajs, J.; Mikielewicz, D.; Jakubowska, B. Performance of the domestic micro ORC equipped with the shell-and-tube condenser with minichannels. *Energy* **2018**, *157*, 853–861. [CrossRef]
88. Erdogan, A.; Colpan, C.O.; Cakici, D.M. Thermal design and analysis of a shell and tube heat exchanger integrating a geothermal based organic Rankine cycle and parabolic trough solar collectors. *Renew. Energy* **2017**, *109*, 372–391. [CrossRef]
89. Shi, L.; Shu, G.; Tian, H.; Deng, S. A review of modified Organic Rankine cycles (ORCs) for internal combustion engine waste heat recovery (ICE-WHR). *Renew. Sustain. Energy Rev.* **2018**, *92*, 95–110. [CrossRef]
90. Zhang, H.; Wang, E.; Fan, B. Heat transfer analysis of a finned-tube evaporator for engine exhaust heat recovery. *Energy Convers. Manag.* **2013**, *65*, 438–447. [CrossRef]
91. Bao, J.; Zhao, L. A review of working fluid and expander selections for organic Rankine cycle. *Renew. Sustain. Energy Rev.* **2013**, *24*, 325–342. [CrossRef]
92. Charnay, R.; Bonjour, J.; Revellin, R. Experimental investigation of R-245fa flow boiling in minichannels at high saturation temperatures: Flow patterns and flow pattern maps. *Int. J. Heat Fluid Flow* **2014**, *46*, 1–16. [CrossRef]
93. Dong, B.; Xu, G.; Li, T.; Quan, Y.; Wen, J. Thermodynamic and economic analysis of zeotropic mixtures as working fluids in low temperature organic Rankine cycles. *Appl. Therm. Eng.* **2018**, *132*, 545–553. [CrossRef]
94. Fergani, Z.; Morosuk, T.; Touil, D. Exergy-Based Multi-Objective Optimization of an Organic Rankine Cycle with a Zeotropic Mixture. *Entropy* **2021**, *23*, 954. [CrossRef] [PubMed]
95. Guo, Q.; Li, M.; Tian, X. Experimental study on flow boiling heat transfer characteristics of R134a, R245fa and R134a/R245fa mixture at high saturation temperatures. *Int. J. Therm. Sci.* **2019**, *150*, 106195. [CrossRef]
96. Zhang, J.; Elmegaard, B.; Haglind, F. Condensation heat transfer and pressure drop characteristics of zeotropic mixtures of R134a/R245fa in plate heat exchangers. *Int. J. Heat Mass Transf.* **2020**, *164*, 120577. [CrossRef]
97. Gullapalli, P.D.V.S. Modeling of brazed plate heat exchangers for ORC systems. *Energy Procedia* **2017**, *129*, 443–450. [CrossRef]
98. Jiménez-Arreola, M.; Wieland, C.; Romagnoli, A. Response time characterization of Organic Rankine Cycle evaporators for dynamic regime analysis with fluctuating load. *Energy Procedia* **2017**, *129*, 427–434. [CrossRef]
99. Wang, E.; Zhang, H.; Fan, B.; Ouyang, M.; Yang, K.; Yang, F.; Li, X.; Wang, Z. 3D numerical analysis of exhaust flow inside a fin-and-tube evaporator used in engine waste heat recovery. *Energy* **2015**, *82*, 800–812. [CrossRef]
100. Carraro, G.; Pili, R.; Lazzaretto, A.; Haglind, F. Effect of the evaporator design parameters on the dynamic response of organic Rankine cycle units for waste heat recovery on heavy-duty vehicles. *Appl. Therm. Eng.* **2021**, *198*, 117496. [CrossRef]
101. Milcheva, I.; Heberle, F.; Brüggemann, D. Modeling and simulation of a shell-and-tube heat exchanger for Organic Rankine Cycle systems with double-segmental baffles by adapting the Bell-Delaware method. *Appl. Therm. Eng.* **2017**, *126*, 507–517. [CrossRef]
102. Jiménez-Arreola, M.; Pili, R.; Wieland, C.; Romagnoli, A. Dynamic study of ORC evaporator operating under fluctuating thermal power from waste heat sources. *Energy Procedia* **2017**, *143*, 404–409. [CrossRef]
103. Kaya, A.; Lecompte, S.; De Paepe, M. Experimental Flow Boiling Study of R245a at High Reduced Pressures in a Large Diameter Horizontal Tube. *Energies* **2022**, *15*, 864. [CrossRef]
104. Wang, J.; Wang, M.; Li, M.; Xia, J.; Dai, Y. Multi-objective optimization design of condenser in an organic Rankine cycle for low grade waste heat recovery using evolutionary algorithm. *Int. Commun. Heat Mass Transf.* **2013**, *45*, 47–54. [CrossRef]

105. Imran, M.; Usman, M.; Park, B.-S.; Kim, H.-J.; Lee, D.-H. Multi-objective optimization of evaporator of organic Rankine cycle (ORC) for low temperature geothermal heat source. *Appl. Therm. Eng.* **2015**, *80*, 1–9. [CrossRef]
106. Walraven, D.; Laenen, B.; D'Haeseleer, W. Optimum configuration of shell-and-tube heat exchangers for the use in low-temperature organic Rankine cycles. *Energy Convers. Manag.* **2014**, *83*, 177–187. [CrossRef]
107. Luo, X.; Xu, J.; Chen, Y.; Mo, S. Mathematical Optimization of the Liquid Separation Condenser Used in the Organic Rankine Cycle. *Energy Procedia* **2015**, *75*, 3127–3132. [CrossRef]
108. Liu, H.; Zhang, H.; Yang, F.; Hou, X.; Yu, F.; Song, S. Multi-objective optimization of fin-and-tube evaporator for a diesel engine-organic Rankine cycle (ORC) combined system using particle swarm optimization algorithm. *Energy Convers. Manag.* **2017**, *151*, 147–157. [CrossRef]
109. Sibalija, T.V. Particle swarm optimisation in designing parameters of manufacturing processes: A review (2008–2018). *Appl. Soft Comput.* **2019**, *84*, 105743. [CrossRef]
110. Ewees, A.A.; Ismail, F.H.; Sahlol, A.T. Gradient-based optimizer improved by Slime Mould Algorithm for global optimization and feature selection for diverse computation problems. *Expert Syst. Appl.* **2023**, *213*, 118872. [CrossRef]
111. Torkan, R.; Ilinca, A.; Ghorbanzadeh, M. A genetic algorithm optimization approach for smart energy management of microgrids. *Renew. Energy* **2022**, *197*, 852–863. [CrossRef]
112. Deb, K.; Pratap, A.; Agarwal, S.; Meyarivan, T. A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE Trans. Evol. Comput.* **2002**, *6*, 182–197. [CrossRef]
113. Li, J.; Liu, Q.; Ge, Z.; Duan, Y.; Yang, Z.; Di, J. Optimized liquid-separated thermodynamic states for working fluids of organic Rankine cycles with liquid-separated condensation. *Energy* **2017**, *141*, 652–660. [CrossRef]
114. Luo, X.; Qiu, G.; Qi, J.; Chen, J.; Wang, C.; Yang, Z.; Chen, Y. Mathematical modelling and structural optimization of a micro-channel liquid separation condenser in organic Rankine cycle and refrigeration cycle. *Appl. Therm. Eng.* **2019**, *152*, 231–246. [CrossRef]
115. Yang, F.; Zhang, H.; Bei, C.; Song, S.; Wang, E. Parametric optimization and performance analysis of ORC (organic Rankine cycle) for diesel engine waste heat recovery with a fin-and-tube evaporator. *Energy* **2015**, *91*, 128–141. [CrossRef]
116. Wang, X.; Damodaran, M. Comparison of Deterministic and Stochastic Optimization Algorithms for Generic Wing Design Problems. *J. Aircr.* **2000**, *37*, 929–932. [CrossRef]
117. Luo, X.; Hu, J.; Zhao, J.; Zhang, B.; Chen, Y.; Mo, S. Multi-objective optimization for the design and synthesis of utility systems with emission abatement technology concerns. *Appl. Energy* **2014**, *136*, 1110–1131. [CrossRef]
118. Li, J.; Peng, X.; Yang, Z.; Hu, S.; Duan, Y. Design, improvements and applications of dual-pressure evaporation organic Rankine cycles: A review. *Appl. Energy* **2022**, *311*, 118609. [CrossRef]
119. Liang, Z.; Liang, Y.; Luo, X.; Chen, J.; Yang, Z.; Wang, C.; Chen, Y. Superstructure-based mixed-integer nonlinear programming framework for hybrid heat sources driven organic Rankine cycle optimization. *Appl. Energy* **2021**, *307*, 118277. [CrossRef]