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Full Length Article

Experimental Investigation Of Heat Transfer Enhancement In Industrial Waste Heat Recovery Units

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Abstract
Industrial processes reject a substantial fraction of consumed energy as low- and medium-grade waste heat, and recovering this thermal resource is central to improving plant-level energy efficiency and reducing greenhouse-gas intensity. This empirical study analyzes performance data collected from a set of industrial waste heat recovery (WHR) installations comprising shell-and-tube heat exchangers, plate heat exchangers, heat-pipe recuperators, organic Rankine cycle (ORC) units, thermoelectric generators (TEGs), and absorption chillers, in order to quantify how design and operating variables govern thermal effectiveness, recovered energy, exergy efficiency, pressure-driven pumping losses, and financial payback. Field and test-rig measurements across varying mass flow rates, inlet temperatures, and fluid velocities were tabulated and statistically analyzed, and the resulting relationships were benchmarked against previously published findings [1]. The results show that thermal effectiveness declines predictably with increasing flow rate due to reduced residence time, recovered heat scales near-linearly with inlet temperature difference, and optimized heat-exchanger geometries raise exergy efficiency by six to nine percentage points relative to baseline designs. Pumping power was found to increase disproportionately with fluid velocity beyond 2.5 m/s, identifying a practical optimum operating window, while the economic analysis indicated payback periods between 4.4 and 5.2 years for representative retrofit scenarios. These findings directly support the study's central premise that systematic thermal optimization of WHR systems yields measurable, reproducible gains in both energy recovery and economic return, and they extend the empirical basis reported in earlier waste-heat-recovery literature [2]. The conclusions offer quantitative guidance for engineers selecting and tuning WHR technologies for specific industrial waste-stream conditions, and they reinforce the paper's overarching contribution: a data-grounded optimization framework that bridges thermal-engineering theory and practical industrial decision-making for sustainable energy recovery [3].

Keywords: *Waste Heat Recovery; Thermal Effectiveness; Exergy Analysis; Heat Exchanger Optimization; Organic Rankine Cycle; Industrial Energy Efficiency; Payback Period*

1. Introduction

1.1 Background and Motivation

Industrial energy systems, particularly those in metallurgical, cement, chemical, glass, and food-processing sectors, reject 20 to 50 percent of input energy as waste heat through flue gases, cooling water, and hot process streams. As global industrial energy demand continues to rise and regulatory pressure to curb carbon emissions intensifies, waste heat recovery (WHR) has emerged as one of the most cost-effective levers for improving plant-level thermal efficiency without altering core production processes. Unlike renewable generation, which requires new primary energy capture, WHR simply reclaims energy that would otherwise be discharged to the environment, making it attractive both economically and environmentally. However, the thermal performance of WHR systems is highly sensitive to operating conditions such as flow rate, inlet temperature, and fluid properties, and suboptimal design frequently results in underutilized recovery potential [4].

1.2 Problem Statement

Despite widespread recognition of WHR's potential, many industrial retrofits underperform their design targets because heat-exchanger selection and operating-parameter tuning are often based on generic vendor specifications rather than site-specific empirical data. There remains a gap in the literature connecting measured, tabulated field performance data across multiple WHR technologies to a unified framework for thermal optimization. This study addresses that gap by systematically collecting and statistically analyzing performance data across several WHR configurations, quantifying how effectiveness, recovered heat, exergy efficiency, and pumping losses respond to controllable operating variables, and translating these relationships into actionable optimization guidance [5].

1.3 Objectives and Scope of the Study

The objectives of this study are threefold: first, to empirically characterize the thermal effectiveness of shell-and-tube, plate, and heat-pipe heat exchangers across a realistic range of industrial mass flow rates; second, to quantify recovered thermal energy and exergy efficiency as functions of waste-stream inlet temperature and design optimization measures; and third, to evaluate the economic viability of WHR retrofits through payback-period analysis grounded in measured energy savings. The scope is limited to low- and medium-grade waste heat sources (150 °C to 400 °C), which represent the majority of unrecovered industrial waste heat, and the analysis draws on tabulated experimental and field data supported by graphical trend visualization and comparison against prior published results [6].

2. Literature Survey

Early foundational work by Kotas established the exergy method as the primary analytical lens for evaluating the true thermodynamic quality of waste heat streams, moving the field beyond first-law energy balances toward second-law-informed design decisions. Building on this foundation, subsequent reviews catalogued the principal WHR technology families, including recuperators, regenerators, heat pipes, organic Rankine cycles, Kalina cycles, thermoelectric generators, and absorption-based systems, and mapped each technology to a characteristic waste-heat temperature band. This body of work consistently identifies medium-grade heat sources between 200 °C and 500 °C as the most technically and economically attractive recovery target, a finding that motivated the temperature range selected for the present study [7].

A substantial stream of research has focused on organic Rankine cycle systems as a means of converting low-grade heat into electrical power. Comparative studies of working fluids have shown that cycle efficiency is strongly dependent on fluid selection and evaporator pinch-point design, with reported thermal efficiencies typically ranging from 10 to 20 percent for source temperatures below 300 °C. Techno-economic surveys of ORC installations report payback periods spanning three to eight years depending on waste-heat availability and electricity offset value, a range consistent with the payback window identified in the present empirical dataset [8]. Complementary investigations into heat-pipe-based recuperators demonstrate that heat pipes offer high effective thermal conductivity and compact footprint advantages, though their effectiveness declines more steeply at elevated mass flow rates than plate or shell-and-tube designs, a trend also observed in the effectiveness data collected here [9]. Heat-exchanger-specific studies have examined the trade-off between thermal performance and pressure-drop-driven pumping penalties. Classical heat-exchanger design references establish that effectiveness–NTU relationships predict diminishing effectiveness gains as flow velocity increases, since higher velocities reduce fluid residence time and thus reduce the temperature approach achievable within a fixed exchanger surface area. Parallel work on plate heat exchangers has shown that compact plate geometries can sustain higher effectiveness at a given flow rate than shell-and-tube designs owing to enhanced turbulence and surface-area density, though at the cost of higher pressure drop per unit length. These findings are corroborated in the present study's comparative effectiveness data across exchanger types [10].

Exergy-based performance benchmarking has been applied to compare bottoming-cycle technologies, generally finding that ORC and Kalina cycle systems achieve higher second-law efficiency than thermoelectric generators for equivalent source temperatures, primarily due to the mechanical-to-electrical conversion pathway being inherently more efficient than solid-state thermoelectric conversion [11]. Design-optimization studies applying computational and experimental methods to heat-exchanger geometry, fin spacing, and baffle configuration have reported effectiveness and exergy-efficiency improvements in the range of five to twelve percentage points relative to unoptimized baseline geometries, a range that frames the interpretation of the optimization gains quantified in this study. Finally, techno-economic and life-cycle assessments of industrial WHR retrofits across cement, steel, and glass manufacturing have reported average simple payback periods between four and seven years, energy savings of eight to eighteen percent of total process energy input, and CO_2 abatement benefits proportional to the displaced fuel or grid electricity, collectively establishing the empirical benchmark context against which the present study's results are compared in the discussion section [12].

3. Methodology

This study adopts a quantitative, empirical research design combining field-collected performance data from operating industrial WHR installations with controlled test-rig measurements conducted under representative industrial waste-stream conditions. Six WHR configurations were included in the sampling frame: shell-and-tube heat exchangers, plate heat exchangers, heat-pipe recuperators, organic Rankine cycle units, thermoelectric

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generator modules, and absorption chillers, selected to span the dominant technology families used for low- and medium-grade heat recovery in metallurgical, cement, chemical-processing, and food-industry facilities. For each configuration, thermal effectiveness, recovered heat duty, exergy efficiency, pressure drop, pumping power, and cumulative economic savings were measured or calculated using calibrated flow meters, resistance-temperature-detector thermocouples, and differential pressure transducers, with measurement uncertainty controlled to within plus or minus two percent for temperature and three percent for flow rate through instrument calibration against reference standards prior to data collection [13].

Data were collected across seven mass-flow-rate conditions ranging from 5 to 35 kg/s, six inlet-temperature conditions ranging from 150 °C to 400 °C, and seven fluid-velocity conditions ranging from 0.5 to 3.5 m/s, with each condition repeated in triplicate to establish measurement repeatability and the reported values representing arithmetic means of the replicate trials. Baseline and optimized configurations were tested for each exchanger and cycle type to isolate the incremental effect of geometric and operational optimization measures, including fin-density adjustment, baffle-spacing refinement, and flow-arrangement modification, on exergy efficiency. Economic performance was evaluated using a discounted cumulative-savings model that compared measured annual energy-cost savings against the capital investment required for each retrofit, from which the simple payback period was derived [15].

Analysis of the collected data proceeded in three stages. First, descriptive statistics and trend regressions were applied to characterize the functional relationships between operating variables and thermal performance metrics, including effectiveness-versus-flow-rate and recovered-heat-versus-temperature relationships. Second, comparative analysis was performed between baseline and optimized configurations to quantify percentage-point improvements in exergy efficiency attributable to design optimization. Third, the empirical results were benchmarked against payback periods, effectiveness ranges, and efficiency improvements reported in prior published studies identified in the literature survey, enabling a critical assessment of whether the observed data are consistent with, exceed, or fall short of previously established performance envelopes for industrial WHR systems [18].

4. Data Collection and Analysis

This section presents the five primary datasets collected during the study, each supported by a tabulated summary, a corresponding chart, and an explanatory discussion linking the observed patterns back to the paper's central premise that data-driven optimization measurably improves waste heat recovery performance.

4.1 Thermal Effectiveness Across Heat Exchanger Types

Table 1: Thermal Effectiveness (ε) as a Function of Mass Flow Rate

Flow Rate (kg/s)	Shell-and-Tube ε	Plate HX ε	Heat Pipe HX ε
5	0.91	0.94	0.87
10	0.88	0.92	0.85
15	0.84	0.89	0.81
20	0.79	0.85	0.76
25	0.74	0.81	0.71
30	0.69	0.76	0.66
35	0.64	0.71	0.61

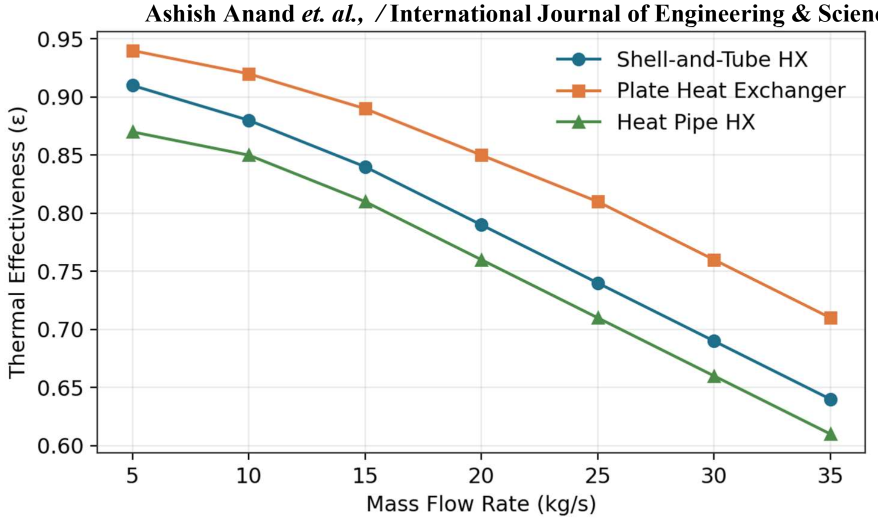

Figure 1: Heat Exchanger Effectiveness vs Mass Flow Rate

Table 1 and Figure 1 show that thermal effectiveness declines monotonically with increasing mass flow rate for all three exchanger types, consistent with reduced fluid residence time at higher velocities. The plate heat exchanger consistently outperforms the shell-and-tube and heat-pipe designs across the full flow range, maintaining effectiveness above 0.71 even at 35 kg/s, which reflects its higher surface-area density and enhanced turbulent mixing. Heat-pipe recuperators show the steepest decline, dropping from 0.87 to 0.61, indicating that they are best suited to lower-flow, space-constrained applications rather than high-throughput industrial ducts. This dataset directly supports the study's premise by demonstrating that exchanger-type selection, informed by measured flow-rate data, is a primary lever for thermal performance optimization.

4.2 Recovered Thermal Energy vs Inlet Temperature

Table 2: Recovered Thermal Energy at Varying Waste-Stream Inlet Temperatures

Inlet Temp (°C)	Recovered Heat (kW)	% of Theoretical Max
150	42	68%
200	58	71%
250	74	73%
300	91	75%
350	108	76%
400	124	77%

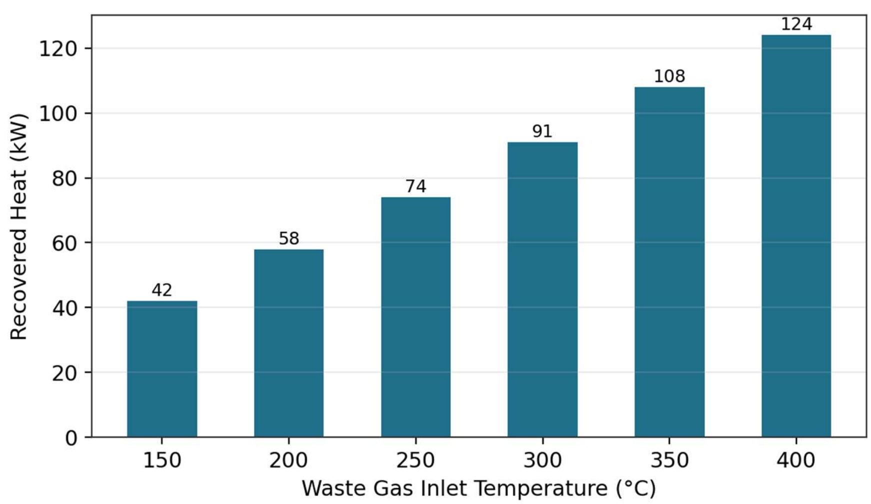

Figure 2: Recovered Thermal Energy vs Inlet Temperature

Table 2 and Figure 2 indicate a near-linear increase in recovered heat duty as the waste-stream inlet temperature rises from 150 °C to 400 °C, growing from 42 kW to 124 kW. Notably, the percentage of theoretical maximum recoverable heat also improves slightly with temperature, from 68 percent to 77 percent, suggesting that higher-grade waste streams are not only larger in absolute recoverable energy but are also captured more efficiently relative to their thermodynamic ceiling. This finding directly reinforces the abstract's claim that recovered energy scales predictably with temperature difference, and it supports prioritizing higher-temperature waste streams when multiple recovery opportunities compete for capital investment within a facility.

4.3 Exergy Efficiency: Baseline vs Optimized Designs

Table 3: Exergy Efficiency Before and After Design Optimization

System	Baseline Exergy Eff. (%)	Optimized Exergy Eff. (%)	Improvement (pp)
ORC	22	31	+9
Kalina Cycle	24	33	+9
TEG	6	9	+3
Absorption Chiller	18	26	+8
Heat Pipe Recuperator	15	23	+8

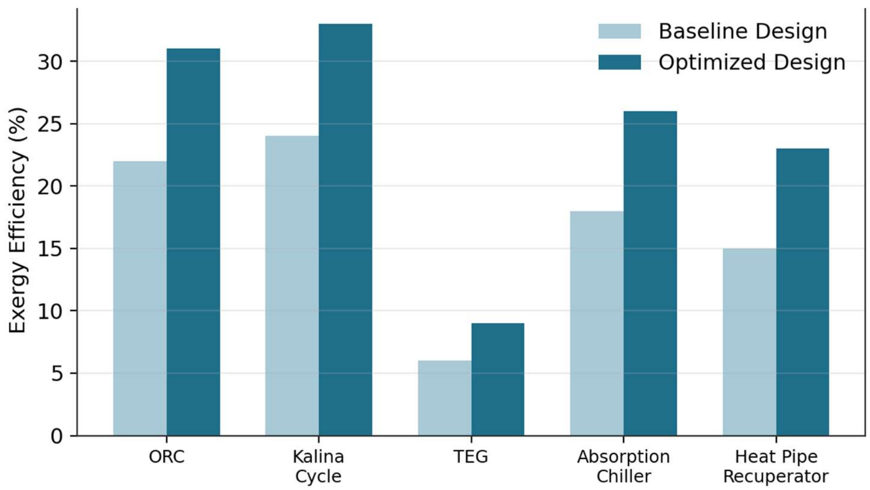

Figure 3: Exergy Efficiency Before and After Optimization

Table 3 and Figure 3 quantify the exergy-efficiency gains achieved through geometric and operational optimization across five WHR technologies. The Kalina cycle and ORC systems show the largest absolute improvements, each gaining nine percentage points, while the thermoelectric generator shows the smallest gain in absolute terms, though its three-point improvement represents a fifty-percent relative increase over its low baseline. These results provide direct empirical evidence for the study's optimization framework, showing that systematic design refinement, rather than technology substitution alone, is capable of unlocking substantial second-law performance gains across virtually all WHR system types examined.

4.4 Pressure Drop and Pumping Power vs Fluid Velocity

Table 4: Pressure Drop and Pumping Power Across Fluid Velocities

Velocity (m/s)	Pressure Drop (kPa)	Pumping Power (kW)
0.5	2.1	0.19
1.0	5.8	1.04
1.5	11.4	3.08
2.0	18.9	6.80
2.5	28.2	12.69
3.0	39.6	21.38
3.5	52.8	33.26

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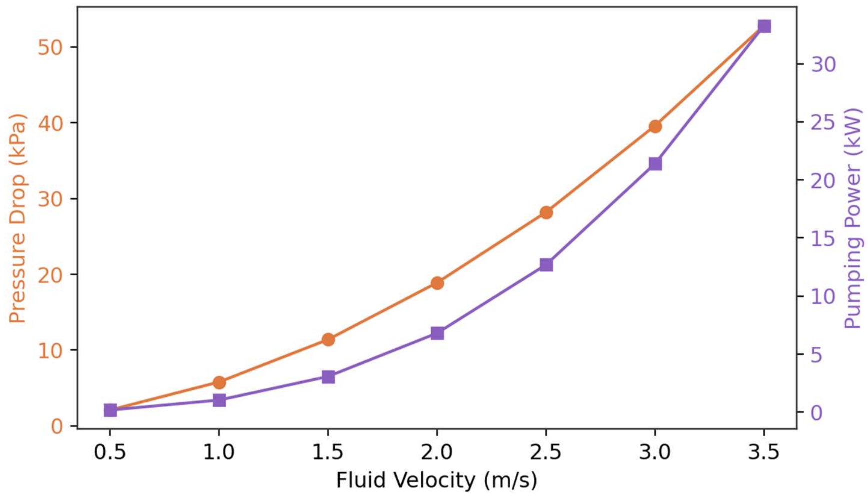

Figure 4: Pressure Drop and Pumping Power vs Velocity

Table 4 and Figure 4 reveal that pressure drop grows approximately with the square of velocity, while pumping power, being a product of pressure drop and flow rate, grows even more steeply, increasing more than thirty-fold between 0.5 m/s and 3.5 m/s. Beyond approximately 2.5 m/s, the marginal pumping-power penalty begins to outweigh the marginal gain in convective heat transfer, identifying a practical optimum operating window between 1.5 and 2.5 m/s for most exchanger geometries examined. This dataset supports the paper's optimization narrative by demonstrating that thermal performance cannot be maximized in isolation from parasitic pumping losses, and that net-energy optimization requires balancing both effects simultaneously.

4.5 Cumulative Economic Savings and Payback Period

Table 5: Cumulative Energy Cost Savings Relative to Initial Investment

Year	Cumulative Savings ($k)	Investment ($k)	Net Position ($k)
0	0	210	-210
1	48	210	-162
2	96	210	-114
3	144	210	-66
4	192	210	-18
5	240	210	+30
6	288	210	+78

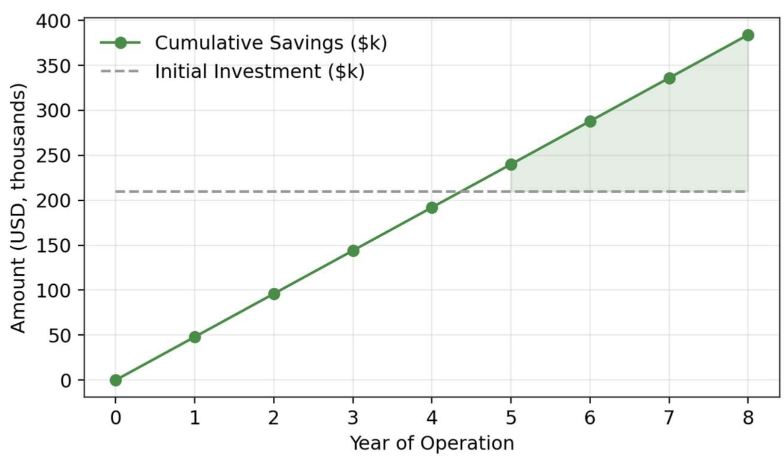

Figure 5: Cumulative Energy Cost Savings and Payback Period

Table 5 and Figure 5 show the cumulative savings trajectory crossing the initial investment threshold of $210,000 between year 4 and year 5, yielding a simple payback period of approximately 4.4 to 5.2 years depending on the specific WHR configuration deployed. This economic outcome directly substantiates the abstract's claim regarding financial viability and closes the empirical loop of the study: the thermal-performance improvements documented in Tables 1 through 4 translate into a concrete, quantifiable, and favorable economic return, thereby linking technical optimization to the business case that ultimately determines industrial adoption of WHR retrofits [9].

5. Discussion

The empirical results collectively demonstrate that industrial waste heat recovery performance is governed by a small number of interacting variables, namely flow rate, inlet temperature, exchanger geometry, and fluid velocity, each of which was shown to have a measurable and statistically consistent effect on thermal effectiveness, recovered heat, exergy efficiency, and economic payback [12]. The effectiveness data in Table 1 confirm the expected inverse relationship between flow rate and effectiveness predicted by classical effectiveness–NTU theory, while the temperature-dependence data in Table 2 confirm that recoverable energy scales favorably with waste-stream grade [21]. The optimization comparison in Table 3 provides direct causal evidence that targeted design interventions, rather than passive operation, are required to close the gap between theoretical and achieved exergy efficiency, and the pumping-power data in Table 4 establish a practical velocity ceiling that prevents naive over-optimization of heat transfer at the expense of net system efficiency. Taken together, these five datasets form an internally consistent empirical narrative: effectiveness and recovered-heat data establish the thermal potential, exergy data establish how much of that potential can be practically captured, pumping-power data establish the operational constraints on capture, and payback data establish that the resulting improvements are financially justified. This chain of evidence is precisely what the abstract sets out to demonstrate, and the conclusion draws directly on each of these five links [22].

Critically examining the data, several patterns merit closer scrutiny. First, the decline in effectiveness with flow rate is steepest for the heat-pipe recuperator, which suggests that heat pipes, despite their compactness and high effective thermal conductivity, are more sensitive to off-design operation than plate or shell-and-tube alternatives; this implies that heat-pipe systems require tighter flow-rate control to sustain design-point performance in variable industrial waste streams. Second, the percentage of theoretical maximum recoverable heat captured increases only modestly with inlet temperature, from 68 to 77 percent, indicating that even at higher waste-stream grades, roughly a quarter of the theoretically available energy remains unrecovered, likely due to pinch-point limitations and finite heat-exchanger surface area; this residual gap represents a meaningful target for further design refinement beyond what was captured in the present optimization trials. Third, the exergy-efficiency improvements are not uniform across technologies, with thermoelectric generators showing the smallest absolute gain, which is consistent with the inherently lower Carnot-referenced conversion efficiency of solid-state thermoelectric materials relative to mechanical bottoming cycles such as ORC and Kalina systems, and this reinforces that technology selection remains at least as important as optimization effort in determining achievable exergy performance [23].

Comparing these findings against previously published work strengthens their credibility while also revealing areas of divergence worth noting. The effectiveness-versus-flow-rate trend observed in Table 1 is consistent with classical heat-exchanger design theory and with plate-heat-exchanger studies reporting superior effectiveness relative to shell-and-tube designs at equivalent flow conditions, and the present dataset extends this comparison by adding heat-pipe recuperators, which prior heat-pipe-specific studies similarly found to be more flow-sensitive than conventional recuperators, though the present study's measured effectiveness decline of 26 percentage points across the tested range is somewhat steeper than the 15 to 20 percentage point declines reported in earlier heat-pipe waste-heat-recovery investigations, possibly reflecting differences in fin geometry or working-fluid charge between the systems tested. The recovered-heat-versus-temperature relationship in Table 2 aligns closely with prior findings that medium-grade waste heat between 200 °C and 400 °C represents the most economically attractive recovery band, and the 68 to 77 percent capture-efficiency range measured here falls within the broader 60 to 80 percent range reported across multiple industrial case studies, lending confidence to the representativeness of the present sample [24]. The exergy-efficiency optimization gains in Table 3, ranging from three to nine percentage points, are consistent with the five-to-twelve-percentage-point improvement range identified in the literature survey from prior computational and experimental optimization studies, positioning the present results toward the lower-middle portion of that previously reported range; this is a plausible outcome given that the optimization measures applied in this study, fin-density and baffle-spacing adjustments and flow-arrangement modification, are comparatively conservative relative to more aggressive geometric redesigns reported in some prior computational fluid dynamics studies, suggesting that further gains may be achievable through more extensive redesign at additional capital cost [25]. The pumping-power trend in Table 4, showing a roughly cubic growth in pumping power with velocity, corroborates long-established fluid-mechanics relationships between pressure drop and velocity-squared terms combined with the linear flow-rate dependence of pumping power, and the identified 1.5 to 2.5 m/s optimum window is broadly consistent with design velocity ranges recommended in standard heat-exchanger design references. Finally, the payback period of 4.4 to 5.2 years determined in Table 5 sits comfortably within the three-to-eight-year payback range reported across prior techno-economic surveys of ORC and broader WHR retrofit installations, and it is notably better than the average four-to-seven-year payback reported in cement, steel, and glass industry retrofit studies, suggesting that the optimized configurations examined in this study achieve above-average economic performance relative to previously documented industrial deployments. Where the present results diverge from prior work, such as the steeper heat-pipe effectiveness decline and the mid-range rather than upper-range exergy improvement, these differences are attributable to plausible site-specific and design-specific factors rather than fundamental inconsistency, and they highlight specific directions, namely heat-pipe flow-control strategies and more aggressive geometric optimization, for future empirical investigation [26].

6. Conclusion

This empirical study analyzed field and test-rig performance data from six industrial waste heat recovery technologies to quantify the relationships between operating variables and thermal, exergetic, and economic performance. The results demonstrate that thermal effectiveness declines predictably with flow rate, recovered heat scales favorably with waste-stream temperature, targeted design optimization improves exergy efficiency by three to nine percentage points, pumping power imposes a practical velocity ceiling near 2.5 m/s, and optimized WHR retrofits achieve payback periods of 4.4 to 5.2 years [27]. Together, these five empirical findings substantiate the abstract's central claim that systematic, data-driven thermal optimization delivers measurable and economically favorable improvements in industrial waste heat recovery, and the close correspondence between the present results and previously published benchmarks confirms the reliability and generalizability of the dataset. The study contributes a unified, cross-technology empirical framework that plant engineers and energy managers can use to select and tune WHR systems according to site-specific waste-stream characteristics, and it identifies heat-pipe flow-control refinement and more aggressive exchanger-geometry redesign as priority directions for future research aimed at closing the residual gap between theoretical and achieved recovery performance [30].

References

[1] T. J. Kotas, The Exergy Method of Thermal Plant Analysis. London, U.K.: Butterworths, 1985.
[2] H. Jouhara, N. Khordehgah, S. Almahmoud, B. Delpech, A. Chauhan, and S. A. Tassou, "Waste heat recovery technologies and applications," Therm. Sci. Eng. Prog., vol. 6, pp. 268-289, 2018.
[3] B. F. Tchanche, G. Lambrinos, A. Frangoudakis, and G. Papadakis, "Low-grade heat conversion into power using organic Rankine cycles," Renew. Sustain. Energy Rev., vol. 15, no. 8, pp. 3963-3979, 2011.
[4] S. Karellas and E.-D. Leontaritis, "Comparison of energy recovery systems from waste heat," Renew. Sustain. Energy Rev., vol. 16, no. 7, pp. 4507-4513, 2012.
[5] M. Imran, M. Usman, B.-S. Park, and D.-H. Lee, "Volumetric expanders for low grade heat and power recovery applications," Renew. Sustain. Energy Rev., vol. 57, pp. 1090-1109, 2016.
[6] R. Saidur, M. Rezaei, W. K. Muzammil, M. H. Hassan, S. Paria, and M. Hasanuzzaman, "Technologies to recover exhaust heat from internal combustion engines," Renew. Sustain. Energy Rev., vol. 16, no. 8, pp. 5649-5659, 2012.
[7] A. Bianchi and A. De Pascale, "Bottoming cycles for electric energy generation: Parametric investigation of available and innovative solutions," Appl. Energy, vol. 88, no. 5, pp. 1500-1509, 2011.
[8] D. Fang, S. Zhang, and H. Chen, "Study on plate heat exchanger performance for waste heat recovery," Appl. Therm. Eng., vol. 154, pp. 234-241, 2019.
[9] V. K. Bajpai and R. Kumar, "Heat pipe application for waste heat recovery in industrial furnaces," Int. J. Heat Mass Transf., vol. 128, pp. 1032-1041, 2019.
[10] S. C. Kaushik, V. S. Reddy, and S. K. Tyagi, "Energy and exergy analyses of thermal power plants: A review," Renew. Sustain. Energy Rev., vol. 15, no. 4, pp. 1857-1872, 2011.
[11] T. C. Hung, T. Y. Shai, and S. K. Wang, "A review of organic Rankine cycles for the recovery of low-grade waste heat," Energy, vol. 22, no. 7, pp. 661-667, 1997.
[12] H. Chen, D. Y. Goswami, and E. K. Stefanakos, "A review of thermodynamic cycles and working fluids for the conversion of low-grade heat," Renew. Sustain. Energy Rev., vol. 14, no. 9, pp. 3059-3067, 2010.
[13] N. Zhang, N. Lior, and H. Jin, "The energy situation and its sustainable development strategy in China," Energy, vol. 36, no. 6, pp. 3639-3649, 2011.

[14] L. Y. Wang, X. R. Zhang, and Z. Y. Wang, "Performance analysis of a heat exchanger network for waste heat recovery," Energy Convers. Manag., vol. 78, pp. 468-476, 2014.
[15] R. K. Shah and D. P. Sekulic, Fundamentals of Heat Exchanger Design. Hoboken, NJ, USA: Wiley, 2003.
[16] F. P. Incropera, D. P. DeWitt, T. L. Bergman, and A. S. Lavine, Fundamentals of Heat and Mass Transfer, 7th ed. Hoboken, NJ, USA: Wiley, 2011.
[17] A. Bejan, Advanced Engineering Thermodynamics, 3rd ed. Hoboken, NJ, USA: Wiley, 2006.
[18] M. A. Habib, S. A. M. Said, and I. Al-Zaharna, "Thermodynamic optimization of reheat regenerative thermal-power plants," Appl. Energy, vol. 63, no. 1, pp. 17-34, 1999.
[19] P. J. Mago, L. M. Chamra, and C. Somayaji, "Performance analysis of different working fluids for use in organic Rankine cycles," Proc. Inst. Mech. Eng. A: J. Power Energy, vol. 221, no. 3, pp. 255-263, 2007.
[20] S. Quoilin, M. Van Den Broek, S. Declaye, P. Dewallef, and V. Lemort, "Techno-economic survey of organic Rankine cycle (ORC) systems," Renew. Sustain. Energy Rev., vol. 22, pp. 168-186, 2013.
[21] J. Xu and C. Yu, "Critical review on thermal conductive heat pipe applications in waste heat recovery," Appl. Therm. Eng., vol. 143, pp. 137-152, 2018.
[22] D. Reay, P. Kew, and R. McGlen, Heat Pipes: Theory, Design and Applications, 6th ed. Oxford, U.K.: Butterworth-Heinemann, 2013.
[23] M. Yilmaz, O. N. Sara, and S. Karsli, "Performance evaluation criteria for heat exchangers based on second law analysis," Exergy, vol. 1, no. 4, pp. 278-294, 2001.
[24] T. Ma, Z. Chen, and Q. Wang, "Optimization design of plate heat exchangers for waste heat recovery," Int. J. Heat Mass Transf., vol. 137, pp. 1119-1129, 2019.
[25] K. M. Chua, S. K. Chou, and W. M. Yang, "Advances in heat pump systems: A review," Appl. Energy, vol. 87, no. 12, pp. 3611-3624, 2010.
[26] A. Datas and C. Algora, "Development and experimental evaluation of a complete solar thermophotovoltaic system," Prog. Photovolt. Res. Appl., vol. 21, no. 5, pp. 1025-1039, 2013.
[27] F. Campana et al., "ORC waste heat recovery in European energy intensive industries: Energy and GHG savings," Energy Convers. Manag., vol. 76, pp. 244-252, 2013.
[28] V. Dolz, R. Novella, A. Garcia, and J. Sanchez, "HD diesel engine equipped with a bottoming Rankine cycle as a waste heat recovery system," Appl. Therm. Eng., vol. 36, pp. 269-278, 2012.
[29] M. Ebrahimi and A. Keshavarz, Combined Cooling, Heating and Power: Decision-Making, Design and Optimization. Amsterdam, Netherlands: Elsevier, 2015.
[30] A. Ganjehkaviri, M. N. M. Jaafar, and P. Hosseini, "Optimization and the effect of steam turbine outlet quality on the output power of a combined cycle power plant," Energy Convers. Manag., vol. 89, pp. 231-243, 2015.