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# Heat Exchangers in Liquid and Industrial Effluent Treatment: A Bibliometric and Thematic Review (1973-2023)

Nyagson L.P. Araújo[1,*], Valéria A.R. Arauz[2], Bruno L. Cruz[3] and Glauber Cruz[1]

[1]*Federal University of Maranhão (UFMA), Coordination of Mechanical Engineering, São Luís, Maranhão, Brazil*

[2]*Federal University of Maranhão (UFMA), Center for Exact Sciences and Technology, São Luís, Maranhão, Brazil*

[3]*Federal Institute of Rio Grande do Sul (IFRS), Center for Exact Sciences and Technology, Porto Alegre, Rio Grande do Sul, Brazil*

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*Corresponding Author
Email: nyagson.lucas@discente.ufma.br
Tel: +55 (98)987530355

## ABSTRACT

Heat exchangers connect wastewater management with energy recovery, yet earlier bibliometric descriptions of this topic have relied heavily on generic title and keyword counts. This study re-examines the literature on heat exchangers in liquid and industrial effluent treatment by combining quantitative science mapping with a content-based thematic review. Records published from 1973 to 15 May 2023 were retrieved primarily from the Web of Science Core Collection; ScienceDirect was used to verify full texts and application-level interpretation. After duplicate removal and relevance screening, 431 records were analyzed in R/RStudio with the bibliometrix workflow. Annual output, source productivity, author productivity, title-term evolution, and application themes were examined. The corpus was historically sparse but expanded sharply in the last decade: 211 records (49.0%) were published during 2014-2023, and annual production peaked at 35 records in 2021. Desalination (25 records) and Water Science and Technology (23 records) were the leading sources, while the most productive authors contributed seven records each, indicating a dispersed rather than highly concentrated research community. The content synthesis identified five modern research streams: heat-integrated water and wastewater networks; wastewater-source heat pumps and sewer heat recovery; fouling, scaling, and material reliability; low-grade-heat-driven separation and disinfection; and data-driven prediction and optimization. The principal unresolved problems are the lack of standardized real-effluent performance benchmarks, limited coupling of heat recovery with biological treatment constraints, scarce open datasets for fouling-aware digital twins, and insufficient techno-economic and life-cycle comparison of competing configurations. The study's contribution is therefore not merely a map of publications, but a specific research agenda linking bibliometric evidence to design, operation, and scale-up decisions for recoverable wastewater heat.

# 1. Introduction

Industrial and municipal wastewaters carry both pollutants and recoverable thermal energy. Heat exchangers enable heating, cooling, pasteurization, heat-pump operation, process integration, and heat recovery without direct mixing of the hot and cold streams. Their performance is governed by temperature driving force, heat-transfer area, overall heat-transfer coefficient, pressure drop, and the evolution of fouling under real water-quality conditions [1-3]. In treatment systems, these variables interact with water reuse targets, sewer hydraulics, biological-process temperatures, maintenance requirements, and the temporal match between heat supply and demand [4-9].

The topic is consequently broader than a catalogue of plate, shell-and-tube, or scraped-surface equipment. Recent research addresses heat-integrated water networks [4-6], wastewater-source heat pumps [7-9], city-scale sewer heat recovery [10-16], predictive models [17,18], fouling control [19], and low-grade-heat-driven treatment technologies [20-26]. These streams have different performance indicators and constraints, which are obscured when bibliometric interpretation is limited to generic words such as “treatment”, “water”, or “heat”.

Bibliometric methods can quantify growth, source dispersion, author productivity, and conceptual structure, but their value depends on transparent data cleaning and on connecting maps to the substantive content of the field [27-30]. The previous version of this work provided a broad historical map but did not clearly distinguish historical activity from current industrial research, did not explain the role of each database, and did not translate bibliometric patterns into specific technical gaps. The revised study addresses those limitations by combining the original 1973-2023 corpus with a focused thematic synthesis of research applications.

The objective is to characterize the development of research on heat exchangers applied to liquid and industrial effluent treatment and to identify design- and operation-relevant directions for future work. The novelty lies in four linked contributions: (i) stratification of the 50-year record to prevent historical publications from dominating interpretation of current trends; (ii) separation of bibliometric indicators from content-level technical evidence; (iii) synthesis of application streams that connect heat-transfer equipment with wastewater processes; and (iv) formulation of a specific, testable research agenda centered on real-effluent benchmarking, thermal-biological coupling, fouling-aware digital twins, and system-level sustainability assessment.

# 2. Technical and Bibliometric Framework

## 2.1. Heat-transfer Performance in Effluent Applications

For a two-stream heat exchanger, the actual heat-transfer rate can be obtained from an energy balance, while the maximum thermodynamically possible rate is limited by the smaller heat-capacity rate. The effectiveness is therefore expressed as [1-3]:

$$\varepsilon = \dot{Q}_{actual} / \dot{Q}_{max} = \dot{Q}_{actual} / [C_{min} (T_{h,in} - T_{c,in})] \quad (1)$$

where $\varepsilon$ is exchanger effectiveness, $\dot{Q}$ is heat-transfer rate, $C_{min}$ is the minimum heat-capacity rate, and $T_{h,in}$ and $T_{c,in}$ are the inlet temperatures of the hot and cold streams. For design or rating calculations, the transferred heat is commonly related to the overall heat-transfer coefficient U, surface area A, and logarithmic mean temperature difference $\Delta T_{lm}$:

$$\dot{Q} = U A \Delta T_{lm} \quad (2)$$

In wastewater service, U is not constant over the operating cycle because suspended solids, dissolved salts, biofilms, fats, and organic matter can create deposits. A technically meaningful comparison must therefore report not only initial heat duty but also the decline of U, pressure-drop increase, cleaning interval, recovery after cleaning, material compatibility, and energy consumed per unit of treated water or recovered heat [2,3,19]. These operational constraints place heat-exchanger design within the broader evolution of wastewater-treatment methods [31]. This operational framing is used below to interpret the bibliometric clusters.

### 2.2. Role and Limits of Bibliometric Analysis

Bibliometric analysis offers reproducible indicators of publication activity and intellectual structure [27-30]. Annual production measures growth, source analysis shows where research is disseminated, author productivity indicates participation and concentration, and term analysis highlights changes in vocabulary. None of these indicators alone demonstrates technical superiority or industrial readiness. Accordingly, the present analysis treats journal and author counts as descriptive, and uses content-based reading of representative records to evaluate applications, constraints, and emerging methods.

## 3. Materials and Methods

### 3.1. Study Design and Data Sources

This study is a bibliometric and thematic review. The quantitative corpus was built from the Web of Science Core Collection because the original analysis retained its export structure for bibliometrix processing. ScienceDirect was used as a complementary source for locating and checking full texts and for validating application-level interpretation. The two resources were not merged as equivalent citation indexes: ScienceDirect is a publisher platform rather than a multidisciplinary citation database. Scopus was not included because a compatible export was not available in the original project and mixing databases without a pre-defined field-harmonization procedure would alter coverage and duplicate handling. This exclusion is acknowledged as a limitation; replication with Web of Science and Scopus using a documented merge protocol is recommended.

### 3.2. Search Strategy and Eligibility Criteria

The search covered publications from 1973 to 15 May 2023. Search combinations included “heat exchanger” with “effluent treatment” or “wastewater treatment”, and equipment-specific variants including “plate heat exchanger”, “shell and tube heat exchanger”, “double tube heat exchanger”, and “twin tube heat exchanger”. English-language journal articles addressing heat exchange, thermal recovery, heating, cooling, or thermally assisted treatment of liquid or industrial effluents were eligible. Records unrelated to liquid-effluent treatment, inaccessible records, and duplicates were excluded. The cleaned dataset contained 431 unique records. The search and analysis protocol is summarized in Table **1**.

**Table 1: Search and analysis protocol.**

| Component | Operational Definition |
|---|---|
| Time span | 1973 to 15 May 2023. |
| Primary bibliographic source | Web of Science Core Collection export used for quantitative analysis. |
| Complementary source | ScienceDirect used for full-text verification and thematic interpretation. |
| Core concepts | Heat exchanger; effluent treatment; wastewater treatment; plate; shell-and-tube; double-tube; twin-tube. |
| Inclusion | English-language journal articles with a substantive link between heat exchange and treatment, recovery, heating, cooling, or reuse of liquid effluents. |
| Exclusion | Out-of-scope records, unavailable full texts for content synthesis, and duplicates. |
| Final corpus | 431 unique records. |
| Software | R/RStudio and bibliometrix [27,32]. |

### 3.3. Data Cleaning and Bibliometric Indicators

Bibliographic records were imported into R and standardized before analysis. Duplicate records and obvious metadata inconsistencies were removed. A record with the author value “NA, NA” was treated as a missing-data artifact and excluded from author rankings. The analysis considered annual scientific production, productivity by source, productivity by author, and the evolution of recurrent title and keyword concepts. Because database category fields can inflate generic labels such as “technology” or “engineering”, interpretive emphasis was placed on field-specific concepts and representative paper content.

### 3.4. Content-based Thematic Synthesis

To address the technical meaning of the bibliometric results, representative papers were selected from recurrent application clusters, leading sources, and the most recent trend window (2014-2023), while retaining earlier landmark contributions where they established a research line. Each paper was coded for the heat source or sink, treatment context, exchanger or thermal-process role, principal operational constraint, and stated research direction. The synthesis was iterative and organized into five streams: integrated water-energy networks; wastewater-source heat pumps and sewer recovery; fouling and reliability; thermally driven treatment; and data-driven analysis. The representative records used in this synthesis are listed in Table **A1** (Appendix A). The complete original BibTeX export should accompany resubmission as Supplementary File S1.

### 3.5. Limitations

The study inherits limitations from the original corpus. Database coverage is restricted, the initial number of hits before deduplication was not preserved in the files supplied for revision, and citation impact could not be normalized by publication year or field. The thematic synthesis is therefore used to strengthen—not replace—the descriptive bibliometric evidence. Future replication should archive the exact search strings, raw exports, screening log, and deduplication decisions in an open repository.

## 4. Results

### 4.1. Corpus Growth and Temporal Structure

The final corpus comprised 431 records published over 51 calendar years. Output was negligible in the earliest period and became progressively more sustained after the mid-1990s. The most recent decade dominated the record: 211 publications (49.0%) appeared during 2014-2023, compared with 103 (23.9%) during 2004-2013, 82 (19.0%) during 1994-2003, 32 (7.4%) during 1984-1993, and only 3 (0.7%) during 1973-1983. Annual output peaked at 35 records in 2021. The 2023 count is incomplete because the search ended on 15 May. The period distribution is summarized in Table **2**, and annual scientific production is shown in Figure **1**.

**Table 2: Distribution of the 431 records by period.**

| Period | Records | Share of Corpus | Interpretation |
|---|---|---|---|
| 1973-1983 | 3 | 0.7% | Historical emergence; isolated applications. |
| 1984-1993 | 32 | 7.4% | Early process and water-treatment integration. |
| 1994-2003 | 82 | 19.0% | Expansion of industrial energy and treatment studies. |
| 2004-2013 | 103 | 23.9% | Consolidation of reuse, optimization, and recovery topics. |
| 2014-2023 | 211 | 49.0% | Current trend window; heat pumps, networks, data-driven models, and low-grade heat. |
| Total | 431 | 100% | Cleaned bibliometric corpus. |

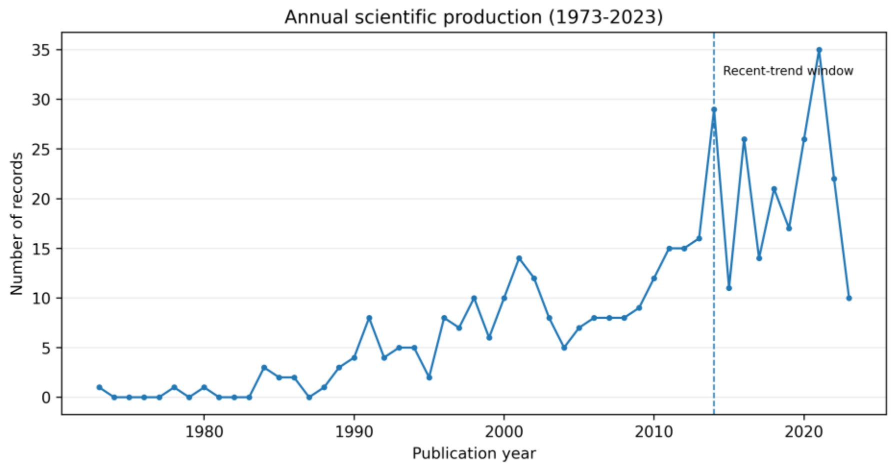


**Figure 1:** Annual scientific production on heat exchangers and liquid/industrial effluent treatment, 1973-2023. The dashed line marks the recent-trend window beginning in 2014.

This stratification changes the interpretation of the 50-year span. The early years are useful as a historical baseline, but they should not be treated as equivalent evidence of present research priorities. The post-2013 period is therefore emphasized in the thematic discussion.

### 4.2. Publication Sources

Research was distributed across thermal engineering, desalination, water treatment, chemical engineering, process systems, and sustainability journals. Desalination led with 25 records, followed by Water Science and Technology with 23. Energy Conversion and Management contributed 12, while Applied Energy and Applied Thermal Engineering each contributed 10. The first five sources accounted for 80 records (18.6% of the corpus), showing that no single journal dominated the field. The complete source ranking is provided in Table **3** and visualized in Figure **2**.

**Table 3: Fifteen most productive sources in the corpus.**

| Rank | Source | Records |
|---|---|---|
| 1 | Desalination | 25 |
| 2 | Water Science and Technology | 23 |
| 3 | Energy Conversion and Management | 12 |
| 4 | Applied Energy | 10 |
| 5 | Applied Thermal Engineering | 10 |
| 6 | Chemical Engineering Journal | 8 |
| 7 | Industrial & Engineering Chemistry Research | 8 |
| 8 | Water Research | 8 |
| 9 | Energies | 6 |
| 10 | Journal of Cleaner Production | 6 |
| 11 | Sustainability | 6 |
| 12 | Chemical Engineering Science | 5 |
| 13 | Chemical Engineering Transactions | 5 |
| 14 | Computer Aided Chemical Engineering | 5 |
| 15 | Process Safety and Environmental Protection | 5 |

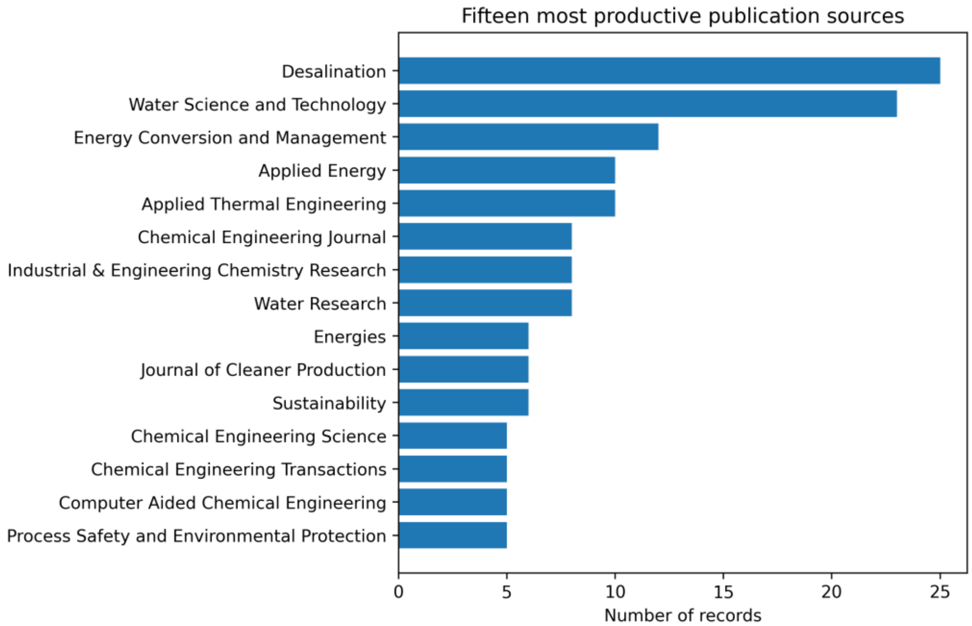


**Figure 2:** Fifteen most productive publication sources in the cleaned corpus.

These counts describe dissemination rather than journal quality or novelty. Their main significance is the multidisciplinary spread: wastewater heat exchange is studied simultaneously as a separation problem, an energy-integration problem, an equipment-design problem, and an environmental-management problem.

### 4.3. Author Productivity

After excluding the missing-author artifact, E. Ahmetović, N. Ibrić, and Z. Kravanja were the most productive authors, with seven records each. Their work is strongly associated with synthesis and optimization of heat-integrated water and wastewater networks [4-6]. The next group contributed five records each, and several authors contributed four. The low maximum relative to 431 records indicates a distributed research community rather than a field controlled by a small set of authors. The author ranking is shown in Figure **3**.

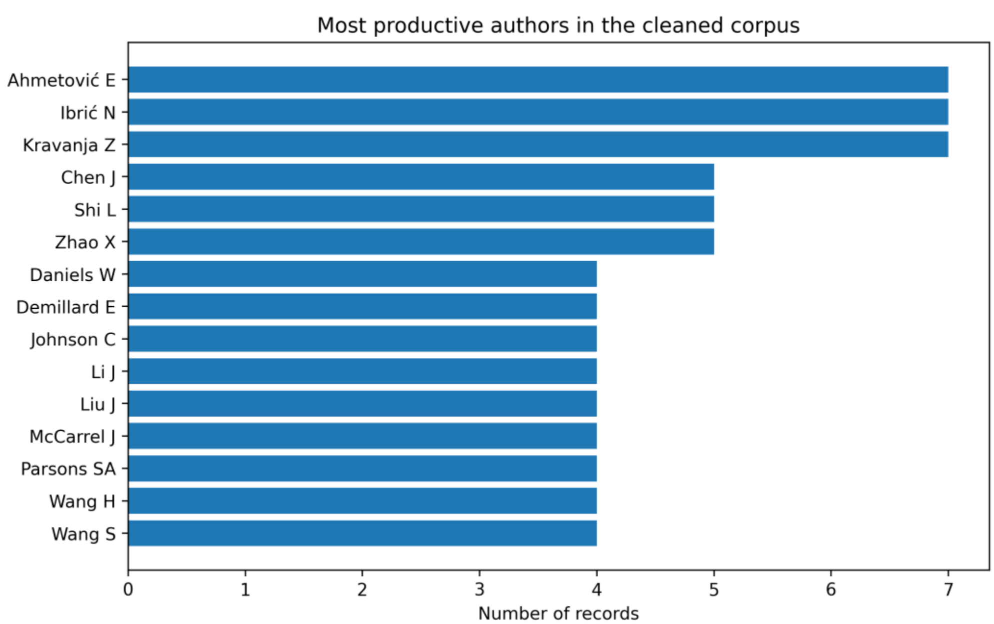


**Figure 3:** Most productive authors in the cleaned corpus. The metadata artifact “NA, NA” was excluded.

### 4.4. Evolution from generic treatment language to system-level research

Title-term analysis showed that "treatment" was the single most frequent title word (38 occurrences), but this generic term alone does not characterize the technical evolution of the field. Comparison of the historical and recent windows showed greater prominence after 2013 of terms related to systems, energy, performance, design, recovery, and wastewater integration. This shift is consistent with the application-level literature: the research focus moved from isolated equipment or treatment descriptions toward integrated energy-water systems, heat-pump applications, process optimization, and operational performance under variable conditions [4-18].

Redundant thematic maps from the previous manuscript were removed because they repeated title vocabulary without revealing application content. The revised synthesis below links each research stream to a technical problem, representative evidence, and an unresolved design or scale-up question. The five application-level research streams are summarized in Table **4**.

### 4.5. Application-level Research Streams

**Table 4: Modern research streams identified through content-based synthesis.**

| Research Stream | Technical Focus | Representative Refs. | Priority Direction |
|---|---|---|---|
| Heat-integrated water and wastewater networks | Simultaneous optimization of water reuse, treatment placement, heat recovery, and exchanger-network topology. | [4-6] | Move from deterministic superstructures to robust, operable networks with water-quality and fouling constraints. |
| Wastewater-source heat pumps and sewer heat recovery | Recovery of low-grade heat from buildings, sewers, treatment-plant influent, and effluent. | [7-16,18,33] | Couple spatial heat demand, sewer hydraulics, minimum biological-treatment temperature, and seasonal uncertainty. |
| Fouling, scaling, and reliability | Decline in heat-transfer coefficient and rise in pressure drop under treated or raw wastewater service. | [19,20] | Develop comparable real-effluent protocols, online fouling indicators, cleanability metrics, and material-selection rules. |
| Thermally driven treatment and disinfection | Use of waste or solar heat for membrane distillation, pasteurization, distillation, and disinfection. | [20-26] | Benchmark net energy, flux decline, pathogen or solute removal, heat-source intermittency, and concentrate management. |
| Data-driven prediction and optimization | Neural-network prediction of influent temperature and exchanger/process performance. | [17,34] | Build physics-informed, uncertainty-aware digital twins that remain valid under changing water quality and operating regimes. |

#### *4.5.1. Heat-integrated Water and Wastewater Networks*

Process-systems research formalized the simultaneous design of water-using, wastewater-treatment, and heat-exchanger networks. The central advance was to recognize that water allocation and energy recovery are interdependent: changing a water-reuse route alters flow rate, contaminant load, inlet temperature, and the feasible exchanger match [4-6]. The mature mathematical formulations are powerful for screening network structures, but industrial implementation requires additional constraints for exchanger fouling, controllability, minimum approach temperature under uncertainty, bypass operation, and maintenance scheduling.

#### *4.5.2. Wastewater-source Heat Pumps and Sewer Heat Recovery*

Wastewater provides a comparatively stable low-grade heat source, and reviews have documented heat-pump arrangements at building, sewer, and treatment-plant scales [7-9]. Subsequent modelling showed that recovery can cool wastewater and thereby affect downstream treatment; the system boundary must therefore include sewer transport and the temperature sensitivity of biological processes [10,11]. More recent city- and plant-wide models incorporate spatial hydraulics, heat losses, seasonal demand, and uncertainty [13-16]. The research frontier is no longer proof that heat exists, but determining where, when, and how much can be recovered without shifting energy or performance penalties downstream.

#### *4.5.3. Fouling, Scaling, and Equipment Reliability*

Fouling is the key distinction between clean-fluid heat-exchanger theory and real effluent service. Scaling-control studies using treated municipal wastewater demonstrate that water chemistry and operating regime affect deposit formation [19]. Pilot membrane-distillation work driven by low-grade waste heat likewise shows that heat recovery and separation performance are inseparable from membrane fouling and cleaning demand [20]. Yet many publications report only initial duty or nominal efficiency. Cross-study comparison requires time-resolved U values, pressure drop, deposit composition, cleaning frequency, water-quality descriptors, and recovery of performance after cleaning.

#### *4.5.4. Low-grade-heat-driven Treatment and Disinfection*

Low-grade waste or solar heat has been evaluated for membrane distillation, refinery-wastewater desalination, pasteurization, solar disinfection, and solar distillation [20-23,26]. These applications expand the role of heat exchangers beyond cooling: they condition feed, recover latent or sensible heat, and stabilize temperature for removal processes. Their sustainability depends on the source temperature, heat-exchanger pinch, auxiliary electricity, intermittency, fouling, and management of rejected contaminants. Reporting gross thermal input without net recovered or avoided energy can overstate benefits.

#### *4.5.5. Data-driven and Hybrid Modelling*

Artificial neural networks have been used to predict wastewater temperature and exchanger-related performance [17,34]. These models can support control and fault detection, but purely empirical models often extrapolate poorly when influent composition, flow, or equipment condition changes. A promising direction is to combine conservation equations, heat-transfer correlations, sewer or reactor models, and machine learning. Such physics-informed digital twins could estimate fouling resistance, forecast recoverable heat, and schedule cleaning while quantifying prediction uncertainty.

# 5. Discussion

## 5.1. What the Bibliometric Evidence Establishes

The corpus demonstrates sustained and accelerating interest, with nearly half of all records published in the last decade of the study. It also shows a multidisciplinary publication base and a dispersed author community. These findings support the conclusion that wastewater heat exchange is an established but still fragmented research area. They do not, by themselves, establish which exchanger design is best. That question depends on wastewater composition, solids, temperature, pressure, hygiene requirements, heat-sink availability, cleaning strategy, and the surrounding treatment process.

The leading publication sources reinforce this interpretation. Desalination and water journals capture treatment and separation applications, whereas energy and thermal-engineering journals capture heat recovery, equipment performance, and system integration. A useful research strategy must bridge these communities rather than using publication counts as a proxy for technical relevance.

## 5.2. Specific Knowledge Gaps

The specific knowledge gaps and corresponding testable research directions are summarized in Table **5**.

**Table 5: Specific gaps and testable research directions.**

| Gap | Why it Matters | Proposed Investigation |
|---|---|---|
| Non-comparable performance reporting | Studies use different fluids, operating times, and indicators; initial efficiency is often reported without deterioration. | Create a minimum reporting standard: influent quality, U(t), pressure drop, heat duty, cleaning interval, thermal and electrical energy, and uncertainty. |
| Weak coupling to treatment biology | Heat recovery is sometimes optimized without enforcing downstream temperature limits for nitrification or other biological processes. | Co-simulate sewer, heat exchanger, heat pump, and biological treatment; optimize recovery subject to process-temperature constraints. |
| Limited fouling-aware design | Fouling factors are commonly assumed rather than learned from time-series data under real effluent conditions. | Develop open multi-site datasets and physics-informed estimators of fouling resistance and remaining clean run-time. |
| Scale mismatch | Component studies do not always include spatial demand, storage, hydraulic capacity, or seasonal operation. | Compare building-, sewer-, plant-, and district-scale recovery using the same functional unit and boundary. |
| Incomplete sustainability evidence | Economic or carbon claims may omit auxiliary pumping, cleaning chemicals, replacement, and concentrate handling. | Perform life-cycle and techno-economic analysis with sensitivity to energy mix, heat price, fouling, and equipment lifetime. |
| Database and reproducibility limitations | Single-index coverage and unavailable raw exports hinder replication. | Publish exact queries, raw exports, deduplication scripts, screening decisions, and coded thematic data as open supplements. |

### 5.3. Novel Research Agenda

The combined evidence supports six concrete research programs. First, an international real-effluent benchmark should compare plate, shell-and-tube, spiral, and self-cleaning or scraped-surface configurations under matched heat duty and water quality. Second, sewer and treatment-plant heat-recovery models should enforce biological-process temperature constraints and quantify where recovery becomes counterproductive. Third, fouling-aware digital twins should integrate online temperature, pressure, flow, and water-quality data with heat-transfer physics. Fourth, modular exchangers for high-solids streams should be evaluated for cleanability and whole-life cost rather than only initial U values. Fifth, hybrid systems combining heat pumps, thermal storage, membrane distillation, or disinfection should be optimized on a net-energy and life-cycle basis. Sixth, a harmonized Web of Science-Scopus corpus with open screening and coding files should be created to support reproducible updating of this review.

These proposals are novel in their integration: each converts a bibliometric trend into a measurable engineering study and specifies the performance variables required to compare alternatives. This is the principal contribution of the revised review.

## 6. Conclusions

This revised bibliometric and thematic review analyzed 431 records on heat exchangers in liquid and industrial effluent treatment from 1973 to 15 May 2023. Publication activity was strongly concentrated in the recent period: 211 records (49.0%) were published during 2014-2023, with a peak of 35 in 2021. Desalination and Water Science and Technology were the leading sources, while the highest author output was seven records, indicating a broad and dispersed community.

The main scientific development is a shift from isolated equipment descriptions toward integrated water-energy networks, wastewater-source heat pumps, sewer and plant-wide modelling, fouling-aware operation, thermally driven treatment, and data-supported optimization. The review also identifies a clear translational gap: published studies rarely use standardized real-effluent benchmarks that combine thermal performance, hydraulic penalty, fouling progression, cleanability, treatment-process effects, economics, and life-cycle impacts.

Future progress should therefore prioritize reproducible real-effluent testing, thermal-biological system models, open fouling datasets, physics-informed digital twins, and scale-consistent sustainability comparisons. By linking quantitative publication patterns with application-level evidence, this study provides a more actionable basis for exchanger selection, research design, and deployment of wastewater heat recovery than keyword mapping alone.

## Author Contributions

**Nyagson L.P. Araújo:** conceptualization, data curation, formal analysis, visualization, writing – original draft.

**Valéria A.R. Arauz:** writing – review and editing.

**Bruno L. Cruz:** writing – review and editing.

**Glauber Cruz:** supervision, methodology, validation, writing – review and editing.

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The authors declare that no specific funding was received for this study.

## Conflict of Interest

The authors declare no conflict of interest.

## Data Availability

The cleaned bibliographic dataset and analysis scripts should be deposited with the final submission as Supplementary File S1. Until deposition, they are available from the corresponding author upon reasonable request.

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# Appendix A. Representative Papers Used in the Content Synthesis

**Table A1: Representative papers used in the content synthesis.**

| Reference | Application | Reason for Inclusion |
|---|---|---|
| [5] | Heat-integrated water/wastewater network | Optimization of water allocation, treatment, and heat recovery. |
| [6] | Heat-exchanger network synthesis | Simultaneous synthesis of water, treatment, and exchanger networks. |
| [7] | Wastewater-source heat pumps | Review of system configurations, performance, and barriers. |
| [8] | Heat exchangers in wastewater heat pumps | Equipment-focused review for building applications. |
| [9] | Wastewater heat resource | Review of resource availability and recovery locations. |
| [10] | Sewer heat recovery | Prediction of sewer temperature response to heat extraction. |
| [11] | Treatment-process effect | Impact of raw-wastewater heat recovery on nitrification and nitrogen removal. |
| [12] | WWTP heat-pump operation | Hybrid heat-pump control for flexible heat recovery. |
| [13] | Plant-wide thermal dynamics | Integration of treatment-plant temperature and sustainable recovery. |
| [14] | Sewer thermal-hydraulics | Distributed heat-transfer model for sewer networks. |
| [15] | Network-scale biological impact | Building heat recovery coupled to sewer and treatment effects. |
| [16] | City-scale uncertainty | Uncertainty-based analysis of urban wastewater heat recovery. |
| [17] | Artificial neural network | Prediction of influent wastewater temperature. |
| [18] | Building and centralized recovery | Interaction between local recovery and centralized energy systems. |
| [19] | Scaling control | Operational control of mineral scaling in exchangers using treated wastewater. |
| [34] | ANN/ANFIS exchanger model | Data-driven prediction for textile-dye recovery heat exchange. |
| [20] | Waste-heat membrane distillation | Pilot performance, fouling, and energy assessment. |
| [21] | Solar membrane distillation | Thermally driven refinery-wastewater desalination. |
| [22] | Pasteurization | Energy and treatment performance for municipal secondary effluent. |
| [26] | Solar distillation | Olive-oil mill wastewater treatment using a parabolic trough collector. |