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ARTICLE

A decade of nanofluid research in chemistry: A bibliometric mapping of trends, themes, and scientific impact

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ABSTRACT

Nanofluid research has expanded rapidly over the past decade, driven by advances in nanoparticle synthesis, interfacial chemistry, and functional fluid design. This study presents a systematic bibliometric analysis of chemistry-oriented nanofluid research to examine publication trends, intellectual structures, and thematic evolution. Scopus-indexed documents published between 2015 and 2024 were analyzed using Microsoft Excel and VOSviewer to identify influential publications, collaboration patterns, and research themes. The results show a shift from early thermophysical optimization toward a chemistry-driven framework emphasizing synthesis routes, stability control, surface functionalization, and molecular-level modeling. Keyword analysis identifies four dominant themes: synthesis and stability, thermophysical chemistry, computational modeling, and hybrid nanofluids. Despite progress, gaps remain in long-term stability, environmental compatibility, and standardized characterization. This study provides a concise chemical perspective and outlines strategic directions for advancing chemically engineered nanofluids.

INTRODUCTION

Nanomaterials have reshaped modern chemical research due to their tunable physicochemical properties and ability to enhance reaction pathways, thermal transport, and interfacial phenomena beyond bulk material limitations. Within this context, nanofluids (engineered suspensions of nanoparticles in conventional base liquids) have gained significant attention for chemical, catalytic, thermal, and biomedical applications because of their enhanced thermal conductivity, stability, and interfacial reactivity (Goharshadi et al., 2013; Angayarkanni & Philip, 2015). These enhancements arise from the high surface-area-to-volume ratio of dispersed nanostructures, which promotes efficient heat and mass transfer, catalytic activity, and advanced reaction engineering (Kulandaivel et al., 2024; Khanafer & Vafai, 2018).

Recent studies demonstrate the growing role of nanofluids in diverse chemical systems. Nanofluids enhance catalytic performance in heterogeneous reactions by strengthening interfacial interactions and modifying thermal environments, while hybrid and magnetically responsive nanofluids show improved performance in heat transfer and biomedical applications (Kameswaran et al., 2012; Hussain et al., 2022). Advances in chemical synthesis, particularly green synthesis, have further enabled the production of nanoparticles with improved stability and reduced environmental impact (Kumari et al., 2015; Cakmak et al., 2020). In parallel, computational approaches such as molecular dynamics simulation and entropy-based modeling have clarified nanofluid behavior in chemically complex environments (Lu et al., 2016; Jabbari et al., 2017; Khan et al., 2020).

Despite these advances, fundamental challenges remain unresolved, including long-term colloidal stability, interfacial chemical reactivity, and the consistency of thermophysical properties under dynamic conditions (Ali et al., 2018). Moreover, studies addressing nanofluid-fluid interactions, reaction-coupled transport phenomena, and environmentally sustainable synthesis remain fragmented and lack integrated chemical perspectives (Kasmani et al., 2015; Hayat et al., 2018). Consequently, a comprehensive chemical-science perspective on nanofluids is still limited in the literature.

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bibliometric analysis, catalysis, chemistry, nanofluid, nanoparticles stability, research trends

Bibliometric analysis provides a systematic approach to mapping scientific structures, thematic evolution, and intellectual linkages. Numerous bibliometric studies have been reported across scientific domains (Al-Obaidi, 2026; Damkan & Chano, 2024; Dewi, 2025; Henny et al., 2025; Nadtayay & Wongsaphan, 2025; Oktaviani, 2025; Oya, 2024; Phuangthanasan & Wongsaphan, 2024; Pujiastuti, 2024; Ruzmetov & Ibragimov, 2023; Samsuri et al., 2025; Sesrita et al., 2025; Srivaro & Jantawee, 2026; Sukarnoor et al., 2026; Susilawati, 2024). Although bibliometric analyses have addressed related areas, comprehensive mapping that explicitly positions nanofluid research within the chemical sciences remains scarce. Such analysis is essential for identifying influential contributors, dominant thematic clusters, and research gaps that can guide future innovation.

Accordingly, this study systematically analyzes publication trends, collaboration networks, and thematic developments in chemistry-oriented nanofluid research over the past decade. By integrating quantitative bibliometric indicators with thematic cluster mapping, this work provides a consolidated knowledge structure and strategic insights for future research. The novelty of this study lies in its explicit chemical-science framing of nanofluid research, combining bibliometric indicators with thematic clustering to reveal linkages between nanoparticle synthesis, interfacial chemistry, catalytic applications, hybrid nanocomposites, and computational advances. Unlike prior reviews focused primarily on thermal, engineering, or biomedical perspectives, this study highlights chemical mechanisms, stability considerations, and synthesis–application pathways that define the evolving scientific landscape of nanofluids.

METHODS

This study employed a systematic bibliometric approach to map research developments in nanofluids within the chemistry domain. Scopus was selected as the data source due to its comprehensive coverage of peer-reviewed literature and reliable metadata.

Data Source and Search Strategy

All bibliographic data were retrieved from the Scopus database, which provides the most comprehensive global coverage for chemical science research. The search was conducted on 21 July 2025, and the query was executed using correct field tags, Boolean operators, and parentheses to ensure replicability. The verbatim search string used in this study was:

"TITLE-ABS-KEY ("Nanofluid") AND TITLE-ABS-KEY ("Chemistry") AND TITLE-ABS-KEY ("Catalysis") OR TITLE-ABS-KEY ("Nanoparticle")"

The publication window was fixed to 2015–2024, as recommended by the reviewer, to maintain consistency across all analyses. This query retrieved all documents in which the term nanofluid appeared in the title, abstract, or keywords, ensuring comprehensive capture of the chemical nanofluid literature while maintaining search precision. In some cases, the dataset was updated to include papers scheduled for imminent publication.

PRISMA-Based Screening and Eligibility Criteria

To ensure transparency and replicability, the dataset was screened following a PRISMA-style process. The steps included:

(i) Identification: records identified via Scopus (initial search across all years), and records matched the 2015–2024 window.
(ii) Screening: Duplicates were automatically removed by Scopus, and non-English papers are excluded.
(iii) Eligibility: Full-text titles and abstracts were screened.
(iv) Inclusion: Studies were retained if they contained chemical relevance, such as: After screening, some documents remained and were used for all bibliometric analyses.

Corpus Cleaning and Chemistry-Focused Filtering

Because the term nanofluid is also used in biomedical, thermal engineering, and fluid mechanics contexts, a de-noising procedure was applied to restrict the corpus to the chemistry domain. Borderline papers were included only if they contained clear chemical elements such as surfactants, zeta potential, chemical bonding, green synthesis, catalytic effects, or nanoparticle modification. The cleaned corpus ensures that all conclusions reflect true chemical nanofluid research.

Data Extraction, Software, and Replicability

All metadata (authors, affiliations, journals, citations, keywords, abstracts) were exported as CSV files. Bibliometric mapping was conducted using: VOSviewer v.1.6.20 (co-authorship, co-citation, keyword networks); Microsoft Excel 2021 (data cleaning, pivot tables).

Analytical Procedures

The bibliometric analysis included: annual publication trends; citation structures; productive journals and publishers; keyword co-occurrence and density mapping; and thematic evolution analysis. Only nanofluid-related data from the chemistry-relevant corpus were used for the calculation of journal outputs, top influential papers, and keyword networks to ensure accuracy and domain specificity.

RESULTS AND DISCUSSION

The bibliometric dataset indicates a transition of nanofluid research from an early exploratory phase toward accelerated, chemistry-driven development (Figure 1). Initial publications were limited to laboratory-scale studies focusing on basic nanoparticle preparation and preliminary thermophysical characterization. As advances in nanotechnology, colloid chemistry, and numerical modeling emerged, research expanded more systematically through improved understanding of nanoparticle–fluid interactions, dispersion stability, and interfacial phenomena (Angayarkanni & Philip, 2015; Ali et al., 2018).

In recent years, rapid publication growth reflects increasing attention to green chemistry, advanced materials, and energy-efficient systems, where nanofluids provide enhanced functional performance beyond conventional heat transfer media (Hedayatnasab et al., 2017; Jabbari et al., 2017; Khan et al., 2020; Cakmak et al., 2020; Hussain et al., 2022). This trajectory highlights the maturation of nanofluid research into a chemically grounded field in which synthesis strategies, surface functionalization, and molecular-level interactions increasingly shape research directions and applications.

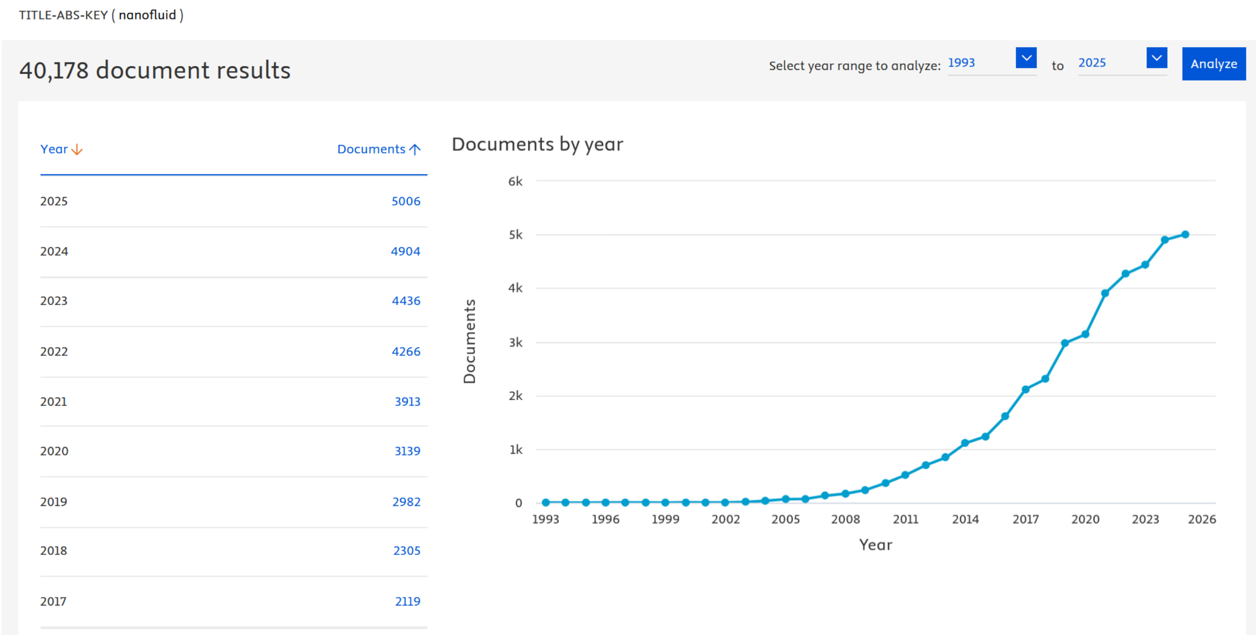

Figure 1: Annual publication trend of nanofluid research in the chemistry domain using the keywords nanofluid based on the Scopus database, retrieved in November 2025.

Citation Landscape and High-Impact Documents

As summarized in Table 1, the citation landscape shows that highly influential contributions to chemistry-oriented nanofluid research are dominated by review articles and mechanistically oriented studies, underscoring the importance of conceptual synthesis and molecular-level understanding in shaping the field (Hedayatnasab et al., 2017; Lu et al., 2016; Jabbari et al., 2017). Review papers achieve high citation impact because they consolidate experimental findings, integrate theoretical frameworks, and identify unresolved challenges related to stability, interfacial interactions, and nanoparticle functionality.

Highly cited experimental studies emphasize chemical synthesis strategies, surface functionalization, and hybrid nanostructure design, demonstrating how chemically engineered nanoparticles influence nanofluid stability, thermophysical behavior, and functional performance (Kumari et al., 2015; Bhatti et al., 2016; Cakmak et al., 2020). These findings indicate that chemical modification (through green synthesis, surfactant-assisted stabilization, or hybridization) plays a critical role in translating nanoscale properties into macroscopic performance.

Computational and modeling-based studies also occupy a prominent position within the citation network, particularly those using molecular dynamics and entropy-based analyses to elucidate nanoparticle-fluid interactions and transport mechanisms (Lu et al., 2016; Jabbari et al., 2017; Khan et al., 2019; Khan et al., 2020). The strong citation impact of these works highlights the growing reliance on predictive chemical modeling to complement experiments and guide rational nanofluid design. The citation structure reflects a field increasingly driven by chemical insight, where synthesis pathways, interfacial chemistry, and molecular-scale modeling jointly define research impact.

Table 1: List of the most influential publications in nanofluid chemistry.

No	Title	Type	Authors
1	Review on magnetic nanoparticles for magnetic nanofluid hyperthermia application	Review	Hedayatnasab et al. (2017)
2	Green synthesis and applications of Au-Ag bimetallic nanoparticles	Article Journal	Kumari et al. (2015)
3	A Critical Review of Dynamic Wetting by Complex Fluids: From Newtonian Fluids to Non-Newtonian Fluids and Nanofluids	Review	Lu et al. (2016)
4	Thermal conductivity and viscosity of nanofluids: A review of recent molecular dynamics studies	Review	Jabbari et al. (2017)
5	Endoscope analysis on peristaltic blood flow of Sisko fluid with Titanium magneto-nanoparticles	Article	Parsa et al. (2015)
6	Effect of substrate temperature on pattern formation of nanoparticles from volatile drops	Article	Yusefi et al. (2021)
7	Green synthesis of Fe3O4 nanoparticles stabilized by a garcinia mangostana fruit peel extract for hyperthermia and anticancer activities	Article	Cakmak et al. (2020)
8	Preparation, characterization, stability, and thermal conductivity of rGO-Fe3O4-TiO2 hybrid nanofluid: An experimental study	Article	Bhatti et al. (2016)
9	Magneto rotating flow of hybrid nanofluid with entropy generation	Article	Khan et al. (2020)
10	Modeling and computational analysis of hybrid class nanomaterials subject to entropy generation	Article	Khan et al. (2019)
11	Thermal enhancement of ribbed double pipe heat exchangers using titanate nanofluids for advanced heat transfer systems	Article	Al-Behadili and Al-Hajjaj (2025)

Country and Institutional Contributions

The global distribution of publications shows a strong geographical concentration of chemistry-related nanofluid research, with Asia as the primary contributor. This pattern reflects sustained investment in nanomaterials synthesis, colloid chemistry, and application-oriented research, supporting large-scale experimental production of nanofluids and hybrid nanostructures. Asian studies predominantly emphasize nanoparticle preparation, stability control, and performance evaluation, aligning with chemistry-driven objectives such as surface modification and functional enhancement (Parsa et al., 2015; Cakmak et al., 2020).

In contrast, research from Europe and North America places greater emphasis on theoretical analysis, molecular-level modeling, and mechanistic interpretation of nanoparticle–fluid interactions, frequently employing molecular dynamics and computational chemistry approaches (Lu et al., 2016; Jabbari et al., 2017). This complementary pattern indicates that experimental synthesis and application pipelines are largely developed in Asia, while mechanistic understanding and predictive modeling are more intensively pursued in Western institutions. These country- and institution-level trends suggest that progress in nanofluid chemistry is driven by the integration of experimental capability and advanced chemical modeling rather than by isolated regional dominance.

Author Productivity and Collaboration Networks

The co-authorship analysis identifies dense collaboration clusters largely organized within national and regional research ecosystems, reflecting shared infrastructure, coordinated funding, and thematic alignment in chemistry-oriented nanofluid research. These intra-country collaborations support strong thematic coherence but may limit methodological diversity. In contrast, cross-country and interdisciplinary collaborations, though less frequent, are associated with higher scholarly impact. Highly cited studies often integrate experimental nanofluid synthesis with computational or theoretical modeling, enabling deeper interpretation of nanoparticle–fluid interactions and interfacial chemistry. The collaboration network suggests that future advances in nanofluid chemistry will increasingly depend on international partnerships that bridge experimental chemistry, materials science, and molecular-level modeling.

Thematic Mapping Through Keyword Co-Occurrence Analysis

The keyword co-occurrence analysis reveals a coherent chemistry-oriented structure of nanofluid research organized into four major thematic clusters (Figure 2):

(i) First cluster (Synthesis and stability): focuses on nanoparticle synthesis, dispersion, and long-term stability, highlighting the roles of surfactant chemistry, surface modification, zeta potential, and green synthesis in controlling interfacial interactions and preventing agglomeration.

(ii) Second cluster (Thermophysical chemistry): emphasizes thermal conductivity, viscosity, and heat transfer behavior, showing that macroscopic performance is governed by chemical parameters such as nanoparticle morphology, surface chemistry, and particle–fluid affinity.

(iii) Third cluster (Computational modeling): comprises molecular dynamics, entropy-based analysis, and numerical simulations that provide molecular-level insight into nanoparticle–fluid interactions and transport mechanisms.

(iv) Fourth cluster (Hybrid and multifunctional nanofluids): highlights hybrid and functionalized systems that extend nanofluids beyond passive heat transfer media toward catalytic, reactive, and multifunctional chemical applications.

The cluster structure and keyword density patterns indicate a maturation of nanofluid research toward a chemistry-driven framework integrating synthesis routes, interfacial chemistry, molecular-level modeling, and functional performance.

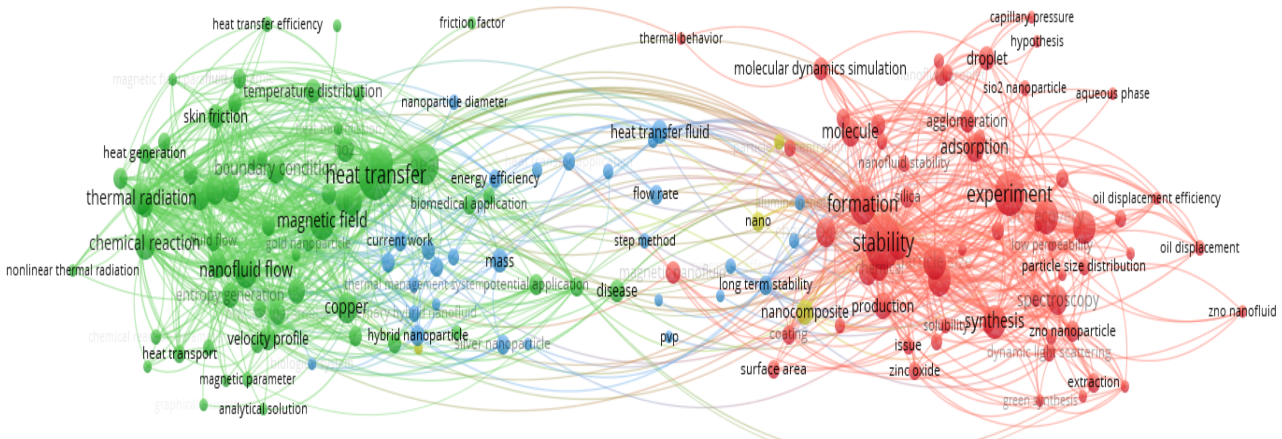

Figure 2: Keyword co-occurrence network of nanofluid chemistry research (2015-2025). Data was retrieved in July 2025.

Structural Distinction between Chemistry-Driven and Engineering-Oriented Nanofluid Research

Nanofluid research shows clear structural differences between chemistry-driven and engineering-oriented perspectives. As summarized in **Table 2**, engineering- and physics-oriented studies primarily emphasize macroscopic performance indicators, such as heat transfer enhancement, flow behavior, and system-level efficiency, whereas chemistry-driven research focuses on molecular and interfacial mechanisms governing nanofluid stability, functionality, and reproducibility.

In chemistry-oriented studies, nanoparticles are treated as chemically engineered entities whose synthesis routes, surface functionalization, and interfacial interactions determine dispersion stability and functional performance. By contrast, engineering-oriented research often treats nanoparticles as effective modifiers of bulk fluid properties, with limited attention to chemical mechanisms underlying long-term stability.

This distinction is reinforced methodologically. Chemistry-driven research frequently integrates experimental synthesis with molecular-level characterization and computational modeling, such as molecular dynamics simulations, to link macroscopic properties with nanoparticle–fluid interactions. Engineering-oriented studies tend to rely on continuum-scale modeling and empirical correlations. These differences indicate that chemistry-driven nanofluid research represents a distinct paradigm in which nanofluids are understood as chemically designed systems rather than passive thermal media.

Table 2: Structural comparison between chemistry-driven and engineering-oriented nanofluid research.

Aspect	Chemistry-Driven Nanofluid Research	Engineering-Oriented Nanofluid Research
Primary research focus	Molecular and interfacial mechanisms governing nanofluid behavior	Macroscopic thermal and flow performance
Central research questions	How synthesis routes and surface chemistry control stability and functionality	How nanoparticles enhance bulk thermophysical properties
Dominant methodologies	Chemical synthesis, surface functionalization, interfacial characterization, molecular-level modeling	Continuum-scale modeling, empirical correlations, system-level testing
Role of nanoparticles	Chemically engineered entities with functionalized surfaces	Effective modifiers of bulk fluid properties
Treatment of stability	Stability as a chemically governed interfacial phenomenon	Stability often treated as an empirical or secondary constraint
Typical application orientation	Catalysis, reactive systems, multifunctional chemical processes	Heat transfer, cooling systems, thermal management

Research Gaps and Opportunities in Chemical Nanofluid Science

As summarized in **Table 3**, chemistry-oriented nanofluid research over the past decade can be grouped into several major research focuses; however, critical gaps remain that limit both fundamental understanding and practical application.

(i) Long-term colloidal stability: remains a persistent challenge affecting reliability, reproducibility, and safety. Most studies focus on short-term stability, while systematic evaluation under extended durations, varying pH, and chemically reactive environments is limited. Standardized metrics integrating zeta potential, sedimentation behavior, and long-term chemical interactions are still lacking.

(ii) Limited integration of interfacial chemistry in predictive models: thermophysical enhancements are widely reported, but chemical mechanisms such as surfactant adsorption, surface energy modification, and nanoparticle–fluid affinity are often oversimplified in theoretical frameworks.

(iii) Environmental compatibility and toxicity: performance-driven studies frequently overlook toxicological effects, biodegradability, and environmental persistence, particularly for chemically functionalized and hybrid nanoparticles.

(iv) Reactive and multifunctional nanofluids: systems designed for catalytic, photocatalytic, or redox activity remain underexplored despite their potential to integrate thermal management with chemical reactivity.

(v) Lack of methodological standardization: variations in synthesis routes, nanoparticle concentration, surfactant selection, pH control, and dispersion protocols hinder reproducibility and cross-study comparability.

Addressing these gaps requires chemistry-driven frameworks that integrate interfacial science, environmental assessment, and standardized methodologies to advance reliable and multifunctional nanofluid systems.

Table 3: Nanofluid research classification in chemistry and its contribution.

No.	Research Focus	Approach/Method	Contribution to Chemistry
1.	Nanoparticle Synthesis for Nanofluids	Green synthesis, solvothermal methods	Development of environmentally friendly synthesis methods that reduce the use of toxic chemicals and enable sustainable material design.
2.	Thermophysical Studies of Nanofluids	Thermal experiments, heat transfer simulations	Characterization of thermal conductivity and viscosity, enhancing understanding of heat transport mechanisms in chemically engineered fluids.
3.	Nanofluid Applications in Catalysis	Photocatalytic and heterogeneous catalytic reactions	Optimization of chemical reaction efficiency, enabling faster rates and selective transformations via active nano-surfaces.
4.	Chemical Interactions Between Nanoparticles and Liquid Media	Spectroscopy, molecular structure analysis	In-depth understanding of interfacial reactivity and chemical bonding behavior between solid-liquid phases.
5.	Influence of Nanoscale Structure on Chemical Reactions	Density Functional Theory (DFT): quantum simulations, XRD	Design of nanoparticle-based catalysts through the correlation of nano-structure with catalytic performance and activity.
6.	Biochemical and Medical Applications (Anti-cancer, Anti-bacterial)	Bioactivity assays, in-vitro testing	Innovation in nanomedicine by using nanofluids for targeted therapies, drug delivery systems, and biomedical diagnostics.
7.	Stability and Chemical Dispersion of Nanofluids	Zeta potential analysis, pH evaluation, surfactant modification	Enhancement of colloidal stability and dispersion quality to ensure practical usability of nanofluids in chemical processes.
8.	Hybrid Nanofluids	Combining two types of nanoparticles	Improvement of thermal and chemical reactivity properties by synergistic effects from hybrid nanostructures.

Integrated Discussion and Implications for Chemical Research
Integrating bibliometric patterns reveals a shift in nanofluid research from thermophysical optimization toward a chemistry-driven framework, where synthesis routes, surface functionalization, and interfacial interactions increasingly determine performance (Angayarkanni & Philip, 2015; Ali et al., 2018). Bibliometric clustering highlights the central role of interfacial chemistry, showing that stability, dispersion, and functional behavior are governed by surfactant chemistry, surface energy modification, and nanoparticle–fluid affinity rather than particle loading alone. The prominence of molecular dynamics and modeling studies reflects a methodological transition toward predictive, chemically informed nanofluid design (Lu et al., 2016; Jabbari et al., 2017). In parallel, the emergence of hybrid and multifunctional nanofluids signals an expansion from passive heat transfer media to chemically active systems relevant to catalysis, reaction engineering, and sustainable chemical processes, underscoring the need for standardized methodologies and long-term stability assessment (Kumari et al., 2015; Cakmak et al., 2020; Hussain et al., 2022).

Conceptual Synthesis of Chemistry-Driven Nanofluid Research
Synthesizing bibliometric patterns and thematic structures shows that contemporary nanofluid research is increasingly governed by chemical design principles rather than empirical thermophysical optimization alone. Dominant themes (including nanoparticle synthesis and stability, interfacial-controlled transport, molecular-level modeling, and hybrid or multifunctional systems) form an integrated conceptual structure in which solid–liquid interfacial chemistry plays a central role.

This synthesis reflects a shift from viewing nanofluids as passive heat transfer media toward chemically engineered systems, where synthesis routes, surface functionalization, and nanoparticle–fluid affinity determine stability, performance, and application potential. Bibliometric evidence indicates that future advances in nanofluid research will depend on integrating interfacial chemistry, predictive modeling, and application-oriented design, providing a unifying conceptual lens for guiding future research directions.

High-Impact Insights Emerging from Chemistry-Oriented Nanofluid Research
Based on integrated bibliometric patterns, thematic structures, and comparative analysis, several high-impact insights emerge that extend beyond existing nanofluid bibliometric reviews.

(i) Nanofluid research is increasingly driven by chemical design principles rather than empirical thermophysical optimization. Bibliometric evidence indicates a structural shift toward synthesis routes, surface functionalization, and interfacial chemistry as primary determinants of stability and performance, reframing nanofluids as chemically engineered systems.
(ii) Interfacial chemistry acts as a unifying mechanism across nanofluid research themes. Stability, dispersion, thermophysical behavior, and multifunctional performance are consistently linked to nanoparticle–fluid affinity, surface energy modification, and surfactant chemistry, explaining inconsistencies in reported properties and limitations of purely macroscopic approaches.
(iii) The convergence of experimental synthesis and molecular-level modeling represents a key driver of high-impact research. Highly cited studies integrate laboratory-scale nanofluid preparation with molecular dynamics and related simulations, supporting predictive and chemistry-informed nanofluid design.
(iv) Hybrid and multifunctional nanofluids mark a strategic expansion beyond conventional thermal management. Chemistry-oriented studies increasingly explore systems combining enhanced thermal transport with catalytic or reactive functionality, identifying hybrid nanofluids as a critical frontier for catalysis, energy conversion, and sustainable chemical processes.

Collectively, these insights position chemistry-driven nanofluid research as a distinct and evolving paradigm that advances beyond descriptive bibliometric mapping and provides a conceptual foundation for future innovation.

CONCLUSION

This bibliometric analysis provides an integrated overview of nanofluid research within the chemistry domain, revealing a clear shift from conventional thermophysical studies toward chemistry-driven investigations emphasizing nanoparticle synthesis, interfacial chemistry, hybrid nanocomposites, and molecular-level modeling. Publication, citation, and collaboration patterns highlight the growing influence of chemically oriented studies and Asia’s leading role in experimental and collaborative research. Thematic mapping identifies four core clusters (synthesis and stability, thermophysical chemistry, computational modeling, and hybrid nanofluid functionality) alongside emerging interests in green synthesis, catalysis-enhanced systems, and biomedical applications. Despite this progress, critical gaps remain in long-term stability, environmental safety, standardized characterization, and predictive chemical modeling. The findings indicate that nanofluid chemistry has matured into a multidisciplinary field with strong potential for advancing reaction engineering, sustainable materials, energy systems, and biomedical innovation, provided future research prioritizes mechanistic insight, standardization, and cross-disciplinary collaboration.

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CONFLICT OF INTEREST

Authors confirm that there is no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

ABDN prepared the manuscript and analysis data,
NACS revised draft, and SRN prepared funds and final check for draft.

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