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Ternary Hybrid Nanofluid Research a Bibliometric Review of Global Evolution and Emerging Prospects

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Abstract:
Thermal management remains a central challenge across modern engineer- ing. Power systems and electronic devices continue to miniaturise while generating greater heat loads. The need for advanced working fluids has intensified as a result. Ternary hybrid nanofluids suspend three distinct nanoparticle species within a single base fluid. They have emerged as a promising response to this challenge. Research output has grown rapidly. Yet a comprehensive bibliometric assessment of this specific field has not previously been published. This study addresses that gap. It presents a systematic bibliometric analysis of the global literature on ternary hybrid nanofluids using data from the Scopus database. The corpus comprises 1,274 articles in the English language indexed up to 7 May 2026. Standard bibliometric indicators and network visualisation through VOSviewer were employed. Publication growth, authorship patterns, country level collabo- ration, citation impact, funding sources, and thematic evolution were all traced. The analysis reveals a sharp increase in scholarly output. Numbers rose from a single article in 2019 to 532 publications in 2025. The Journal of Thermal Analysis and Calorimetry and Case Studies in Thermal Engineering emerge as the most productive outlets. The latter records the highest citation count. Saudi Arabia, India, Malaysia, China, and Pakistan appear as the most active contributing nations. King Khalid University and King Saud University stand out as both leading publishers and principal funding bodies. Keyword analysis shows a distinct thematic shift. The field is moving away from purely fundamental investigations toward application driven research. Intelligent modelling through neural networks, plasma flow environments, phase change heat transfer, advanced cooling technologies, and biomedical applications all feature prominently in this trend. The novelty of this work lies in delivering the first integrated bibliometric mapping dedicated specifically to ternary hybrid nanofluids within fluid dynamics. Publication dynamics, collaboration structures, funding landscapes, and thematic trajectories are combined into a single coherent framework. The study offers researchers a practical reference for journal selection, partnership identification, funding exploration, and future direction setting in this rapidly expanding domain.

Keywords: Ternary hybrid nanofluid Bibliometric analysis VOSviewer Thermal Management Funding Sources Research trends Scientific publications.

Introduction

Thermal management has become one of the more pressing concerns in contemporary engineering. Power electronics, compact energy systems, and industrial equipment that operates at high throughput all produce thermal loads that conventional coolants find difficult to manage. The gap between what existing fluids deliver and what engineers actually need is widening steadily

[1]. This problem manifests across a remarkably wide range of sectors. HVAC installations, solar thermal systems, shell and tube heat exchangers, microprocessor cooling assemblies, biomedical instrumentation, refrigeration units, vehicle thermal circuits, and chemical reactors all depend to varying degrees on the thermal transport properties of their working fluids [2, 3].

The trajectory of nanofluid research is usually traced to Choi and Eastman [4]. Their pioneering work showed that seeding a base fluid with particles at the nanometre scale produces a measurable gain in thermal conductivity. That result opened a productive line of enquiry. Researchers tested metallic particles, metal oxides, and carbon derivatives alike, dispersing them into water, ethylene glycol, engine oil, and various industrial coolants while recording how each combination altered heat transport behaviour [5]. Interest in these nanofluids has held firm over the years. This is largely because they raise effective thermal conductivity and convective transfer coefficients well above what the base fluid alone could achieve [6].

Hybrid nanofluids followed as a natural extension. Rather than dispersing a single nanoparticle type, hybrid formulations combine two different solid species within the same carrier fluid. The resulting mixtures tend to outperform their single component predecessors on most thermal metrics [7]. Solar collectors, heat pipes, refrigeration loops, machining operations, HVAC equipment, automotive cooling systems, and electronic thermal management units have all served as testing grounds for hybrid nanofluid studies [8].

More recently, a further step has been taken. Ternary hybrid nanofluids carry three distinct nanoparticle species in simultaneous suspension, and they have begun drawing serious research attention. The appeal is straightforward. Three component systems open the possibility of thermophysical improvements that binary or mono formulations simply cannot match [9, 10]. What makes ternary systems genuinely interesting is not merely that a third particle type is added. Rather, the three components, typically drawn from metallic, oxide, and carbon based families, interact in ways that produce thermophysical synergies unattainable in simpler mixtures [11, 12]. Thermal conductivity rises. So do dynamic viscosity, density, and specific heat capacity, provided the constituent materials and their volume fractions are chosen with care. These properties make ternary hybrid nanofluids well suited to situations where heat loads are extreme or where the margin for thermal error is narrow [13]. It is therefore unsurprising that the literature now documents their behaviour across a wide range of flow configurations. Flat plates, stretching and shrinking surfaces, parallel channels, curved and annular passages, rotating geometries, and environments at stagnation points have all been studied, with enhanced thermal performance reported consistently across these settings [14].

Applications outside classical thermal engineering have also emerged. Power generation, biomedical technology, solar energy systems, microelectronics, and chemically reactive flow processes where precise temperature control is absolutely essential have all been proposed as viable deployment areas [15]. The tuneable nature of these fluids has in turn attracted interest from the computational modelling community. Artificial neural networks and response surface methods are increasingly used to predict and optimise their thermal behaviour under varied operating conditions[16].

Yet the field, for all its activity, is still young. A clear and structured picture of its global intellectual landscape has not yet emerged. Publication numbers are climbing fast. That growth is spread unevenly across dozens of journals, a wide variety of application domains, and several competing methodological traditions. Identifying which authors are most influential, which countries lead in output or collaboration, which institutions anchor the research community, and how the major themes interconnect is not something that can be done by reading abstracts alone.

Bibliometric analysis is well suited to this kind of task. It works by systematically quantifying the scholarly output of a field and then mapping the relationships between authors, institutions, keywords, and cited works that give that field its structure [17, 18]. Software such as VOSviewer translates these relationships into visual networks. Keywords that appear together reveal thematic groupings. Coauthorship maps expose collaboration patterns. Citation analysis of jointly referenced works surfaces the papers that the community treats as foundational [19]. For a field like ternary hybrid nanofluids, where the literature is growing faster than it can be surveyed by conventional means, these tools are not a luxury. Publication trends, citation profiles, geographic distributions, and keyword dynamics together make visible both where the field is heading and where the mean- ingful gaps lie. These gaps call for targeted modelling, simulation studies, or new experimental programmes.

No bibliometric study has yet addressed ternary hybrid nanofluids as a distinct research domain within fluid dynamics. That absence is the gap the present work sets out to fill. Using publication data retrieved from the Scopus database, specifically 1,274 articles in the English language indexed up to 7 May 2026, this study maps the global literature on ternary hybrid nanofluids through network visualisation using VOSviewer alongside standard bibliometric indicators. The analysis covers publication growth over time, authorship and coauthorship structures, collaboration patterns among countries, citation impact, and the clustering of keywords that appear together. Each dimension is examined for what it reveals about the current state of the field and where productive future work might be directed.

Methodology and Data Extraction

Sample Selection Process

All bibliometric data analysed in this study were drawn from the Scopus database. The selection of Scopus over alternative sources was deliberate. Its coverage of engineering and applied science literature is extensive. Its metadata are consistently structured. Its citation records are sufficiently complete to support the relational mapping that a still developing field like ternary hybrid nanofluid research demands [20]. The availability of author affiliation data, source journal information, and citation linkages further ensures that the analyses can be carried out in a transparent and reproducible manner [21].

Relevant publications were identified through the Scopus advanced search interface. The query string used was the following.

> TITLE-ABS-KEY("ternary hybrid nanofluid" OR "tri-hybrid nanofluid" OR "trihybrid nanofluid" OR "ternary nanofluid")

The search was run on 7 May 2026. No restriction was placed on publication year. Two filters were then applied sequentially. Document type was restricted to article. Language was restricted to English. Limiting the corpus in this way is standard practice in bibliometric research. It confines the dataset to peer reviewed scholarly output and reduces noise introduced by grey literature [22]. Withdrawn records, editorials, conference papers, and book chapters were all excluded from further consideration.

Data Cleaning and Final Dataset

The unfiltered query returned 1,332 records. The English language restriction removed one record, leaving 1,331. Filtering by document type cut the count further to 1,274 peer reviewed journal articles. This final dataset of 1,274 papers served as the analytical foundation for every indicator, network, and visualisation reported here.

Bibliometric Indicators

To characterise the global research landscape on ternary hybrid nanofluids, the following bibliometric indicators were examined.

- Annual publication output, to trace growth trends across the study period.
- Most productive authors and institutions, ranked by total document count.
- Leading countries by publication volume and international collaboration frequency.
- Most cited documents and journals, to pinpoint core references and the principal outlets through which the field disseminates its findings.
- Funding sources, to establish which bodies have most actively supported research in this domain.
- Thematic clustering based on keywords that appear together, to map dominant and emerging research themes.
- Recent publication trends, to highlight directions attracting growing attention at the current frontier of the field.

Analytical Tools and Network Construction

The Scopus dataset was exported in CSV format and imported into VOSVIEWER. This is a well-established platform for bibliometric network construction and visualisation [23]. Five distinct network types were generated in the course of the analysis.

- Coauthorship networks, constructed at both the individual author and country levels.
- Cocitation networks for cited references.
- Maps showing which keywords appear together, based on author supplied index terms.
- Funding sponsor networks, to identify the bodies most frequently supporting work in this area.
- Temporal overlay maps, allowing the chronological evolution of research themes to be examined visually.

For each network type, minimum threshold values were set. These governed the minimum number of documents per analytical unit and the minimum number of keyword occurrences. The goal was to ensure that only sufficiently represented entities appeared in the final maps. It also ensured that the resulting visualisations remained interpretable [24]. The networks were then interrogated to identify dominant thematic clusters, emergent research directions, active funding organisations, and areas where the literature remains sparse.

Publication Trends and Subject Distribution

The bar graph in Figure 1 presents the annual publication output for ternary hybrid nanofluid research between 2019 and 2026. In the earliest years, activity was sparse. A single article was recorded in 2019. Five appeared in 2020. 21 were published in 2021. The trajectory shifted markedly from 2022 onward. Output rose to 64 articles that year. Then it accelerated to 286 in 2024. The peak came in 2025 with 532 publications. This figure represents roughly 41.76% of the entire corpus. The 2026 count is lower by comparison. That simply reflects the fact that data collection was completed in May of that year. The annual total was still accumulating at the time of retrieval. It should not be read as a sign of waning interest. Across the full period, the trend is clear. Ternary hybrid nanofluid research has matured from a niche area into one of the more rapidly expanding subfields in fluid dynamics and thermal engineering.

The subject distribution shown in the pie chart (Figure 2) is directly obtained from Scopus. Which confirms the predominantly engineering driven character of the field. The range of contributing disciplines is broader than might be expected. Physics, chemical engineering, mathematics, materials science, and chemistry each account for a meaningful share of the literature. This reflects the theoretical depth and applied orientation that coexist within this research domain. Contributions from computer science and energy related subjects signal a growing reliance on numerical modelling, computational optimisation, and energy system applications. More striking, perhaps, are the smaller but measurable contributions from environmental science, medicine, and biological sciences. These indicate that the reach of ternary hybrid nanofluid research is beginning to extend beyond conventional heat transfer contexts into domains that were, until recently, quite distant from the field's original concerns.

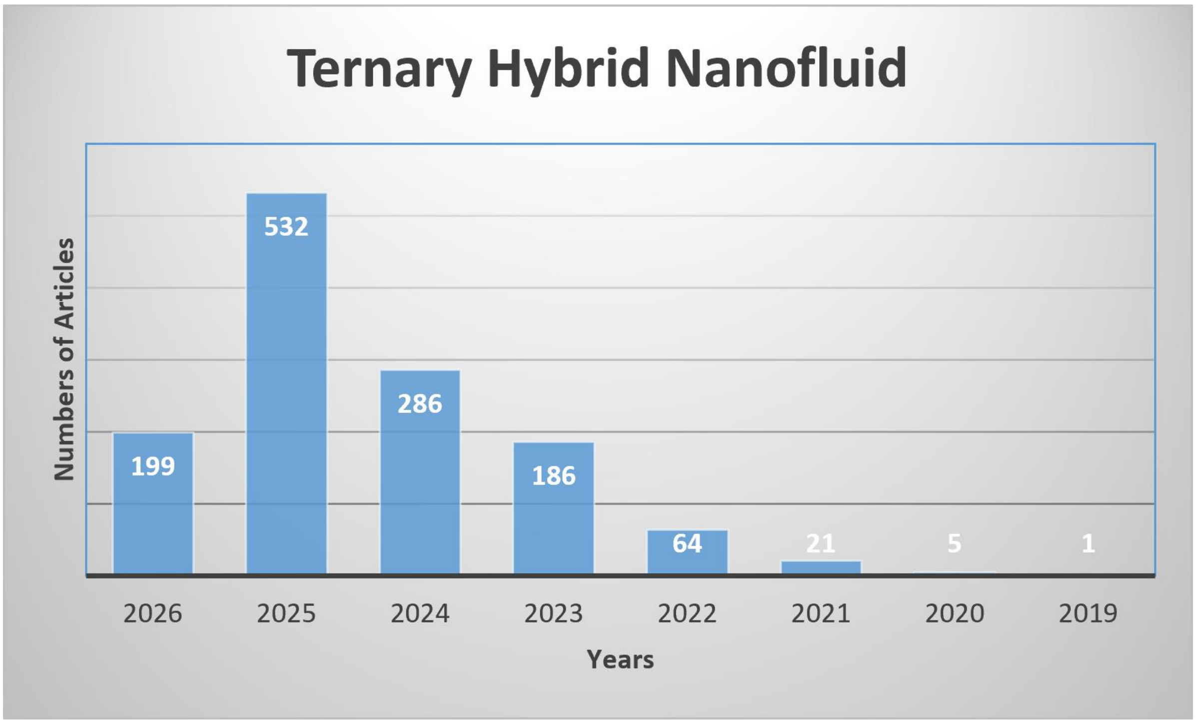

Figure 1: Annual distribution of ternary hybrid nano uid publications.

Figure 2: Pie chart representing the proportion of research in broad subject categories within ternary hybrid nano uid studies.

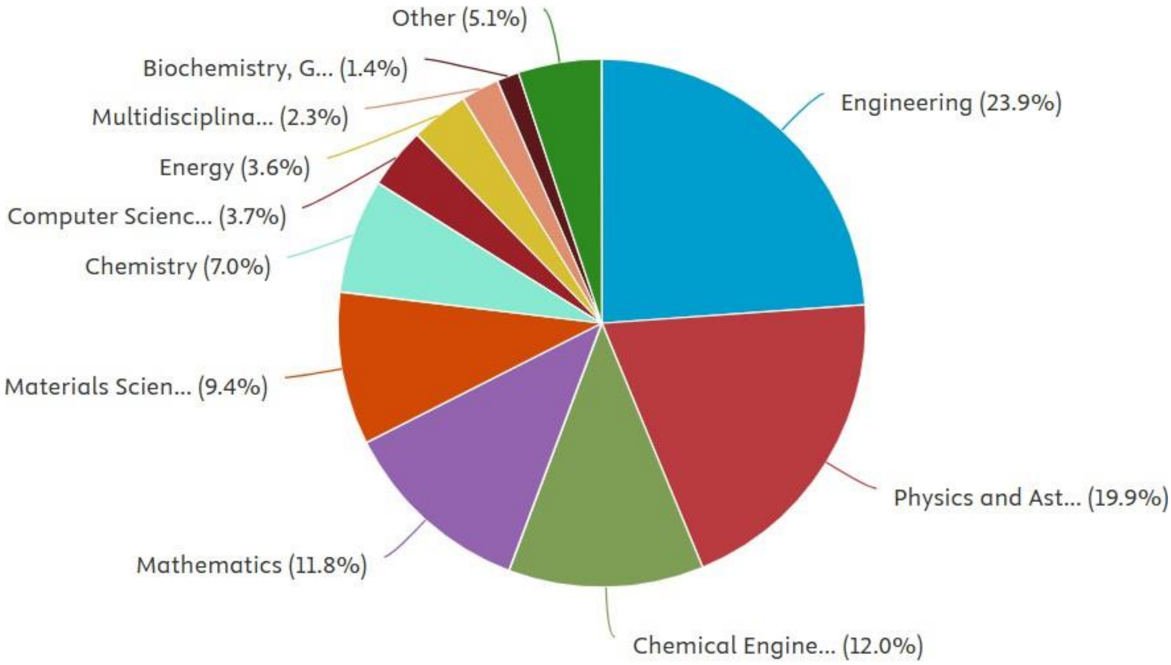

Figure 2: Pie chart representing the proportion of research in broad subject categories within ternary hybrid nano uid studies.

Results and Discussion

Core Journals and Citation Impact

The publication landscape for ternary hybrid nanofluid research is concentrated within a recognizable set of well-established outlets. Most of these are oriented toward thermal engineering, heat transfer, fluid mechanics, or applied mathematics. The ten most productive journals are listed in Table 1.

The Journal of Thermal Analysis and Calorimetry leads in terms of document count. It has published 95 articles on the subject. Case Studies in Thermal Engineering follows closely with 90 documents. This journal also recorded the highest total citation count among all outlets. It accumulated 2,535 citations. This speaks to the visibility and reach that publications in this venue tend to attract within the community. Other journals contributing substantially to the corpus include Numerical Heat Transfer, Part A: Applications, Results in Engineering, and the International Journal of Thermofluids. Each of these has established itself as a recurring destination for work in this domain.

The cocitation network presented in Figure 3 adds a relational dimension to these counts. The connections among core journals are dense. They reflect the tight intellectual ties that characterise the field's publication culture. Journal of Thermal Analysis and Calorimetry and Case Studies in Thermal Engineering emerge as two of the most heavily connected nodes in this network. International Communications in Heat and Mass Transfer, ZAMM Zeitschrift für Angewandte Mathematik und Mechanik, and Journal of Molecular Liquids also occupy structurally significant positions. The pattern of cross journal citation linkages suggests that ternary hybrid nanofluid research does not sit comfortably within a single disciplinary silo. Rather, it draws from and contributes to several adjacent scientific communities simultaneously. This characteristic likely broadens its overall citation reach.

For researchers planning future submissions, these findings carry a practical implication. Case Studies in Thermal Engineering and Journal of Thermal Analysis and Calorimetry represent the two venues most likely to maximise readership exposure within the ternary hybrid nanofluid community. This is due to their combination of high output and citation performance. Journals exhibiting high total link strength in the cocitation map further suggest active scholarly communication among their contributor communities. Numerical Heat Transfer, Part A: Applications is a notable example. This level of connectedness may translate into faster uptake of newly published work.

Table 1

Top 10 leading journals in ternary hybrid nano uid research.

Rank	Journal	Docs	Cites	TLS
1	Journal of Thermal Analysis and Calorimetry	95	923	31
2	Case Studies in Thermal Engineering	90	2535	9
3	Results in Engineering	42	380	3
4	Numerical Heat Transfer Part A Applications	43	561	11
5	International Journal of Thermo uids	36	447	4
6	Scienti c Reports	34	768	5
7	ZAMM Zeitschrift fur Angewandte Mathematik und Mechanik	58	359	2
8	International Communications in Heat and Mass Transfer	26	1133	8
9	Journal of Molecular Liquids	18	715	1
10	Applied Thermal Engineering	10	207	4

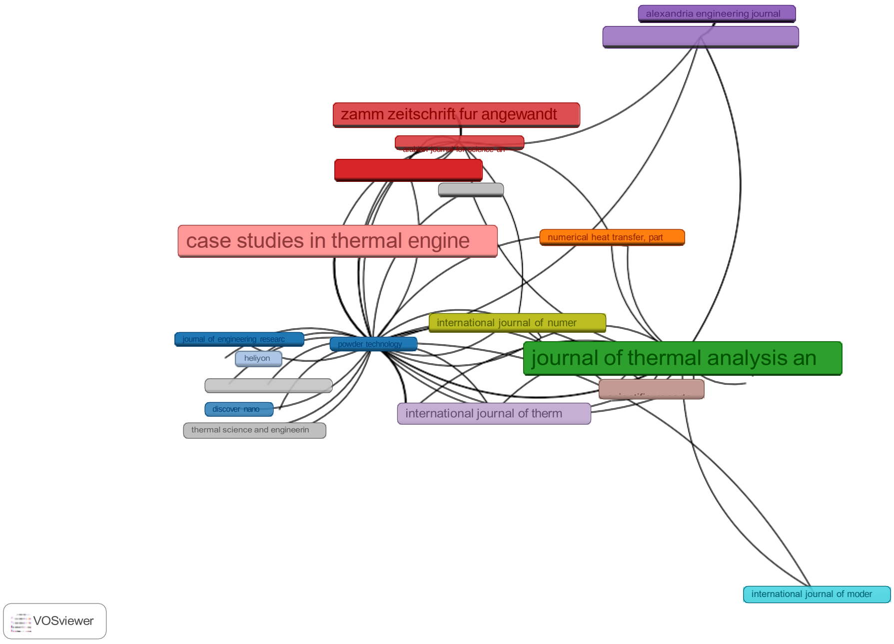

Figure 3: Citation source network map highlighting leading journals in ternary hybrid nano uid studies.

Cocitation Analysis of References

The intellectual foundations of this field become visible through cocitation analysis. Results appear in Table 2. The most frequently cocited work is that of Eastman and Choi. Their introduction of the broader nanofluid concept established the conceptual groundwork upon which later investigations have built. Among publications dealing specifically with ternary hybrid nanofluids, the review by Dagbasi et al. stands out. Its citation count and total link strength are the highest recorded for any domain specific reference. This marks it as a central bridge connecting the foundational nanofluid literature to the more recent ternary hybrid subfield.

The thematic content of the most highly cited papers reflects the applied and modelling oriented character that this research has assumed over time. Topics represented among these core references include thermoeconomic performance evaluation, radiator heat transfer, evaporative cooling systems, magnetohydrodynamic flow, and nonlinear thermal radiation effects. The prevalence of such subjects signals that the field has moved well beyond purely descriptive thermophysical characterisation. Instead, researchers are increasingly engaging with questions of system level optimisation and real world thermal management. They draw on ternary hybrid nanofluids as tools within larger engineering problems.

The cocitation network visualised in Figure 4 reinforces these observations. The map is well connected. A small number of studies with high citation counts function as structural anchors for the broader intellectual space. The work of Eastman and Choi [25] occupies one of the most prominent nodal positions in the network. This is a testament to the enduring influence of the original nanofluid concept on later ternary hybrid investigations. The review by Dagbasi et al. [26] serves a different but complementary role. Its dense linkages to subsequent literature position it as a hub through which work on nanofluid synthesis, colloidal stability, and thermal transport behaviour is interconnected.

Surrounding these anchoring nodes, a cluster of application and modelling studies displays tight mutual citation linkages. These include Kumar et al. [27], Sahoo et al. [28], Kumar et al. [29], Mostafa et al. [30], Mathew et al. [31], and Gul et al. [32]. Shared themes of radiator performance, thermal transport, magnetohydrodynamic flow, nonlinear radiation, and thermoeconomic analysis recur across this cluster. This suggests a degree of methodological and thematic convergence within this segment of the literature. The presence of these elements among the cited methodological references is also noteworthy. It indicates that the community draws not only on physical modelling frameworks but also on numerical techniques developed for complex flow and heat transfer problems.

Taken together, the cocitation map points to a field that is intellectually coherent and increasingly self referential. A compact set of foundational and review level publications shapes the conceptual vocabulary and methodological toolkit of the domain. Newer contributions consistently return to these sources as common reference points. This pattern of convergence around a stable citation core suggests that the research is consolidating. It is building cumulatively on established results rather than expanding in fragmented or disconnected directions.

Table 2

Top 10 most co-cited references in ternary hybrid nano uid research.

Rank	Cited reference	Citations	Total link strength
1	Eastman and Choi [25]	98	40
2	Dagbasi et al. [26]	63	80
3	Kumar et al. [27]	43	78
4	Sahoo et al. [28]	43	70
5	Kumar et al. [29]	38	44
6	Mostafa et al. [30]	36	53
7	Mathew et al. [31]	31	39
8	Gul et al. [32]	29	26
9	Krawczuk et al. [33]	26	10
10	Wang et al. [34]	43	78

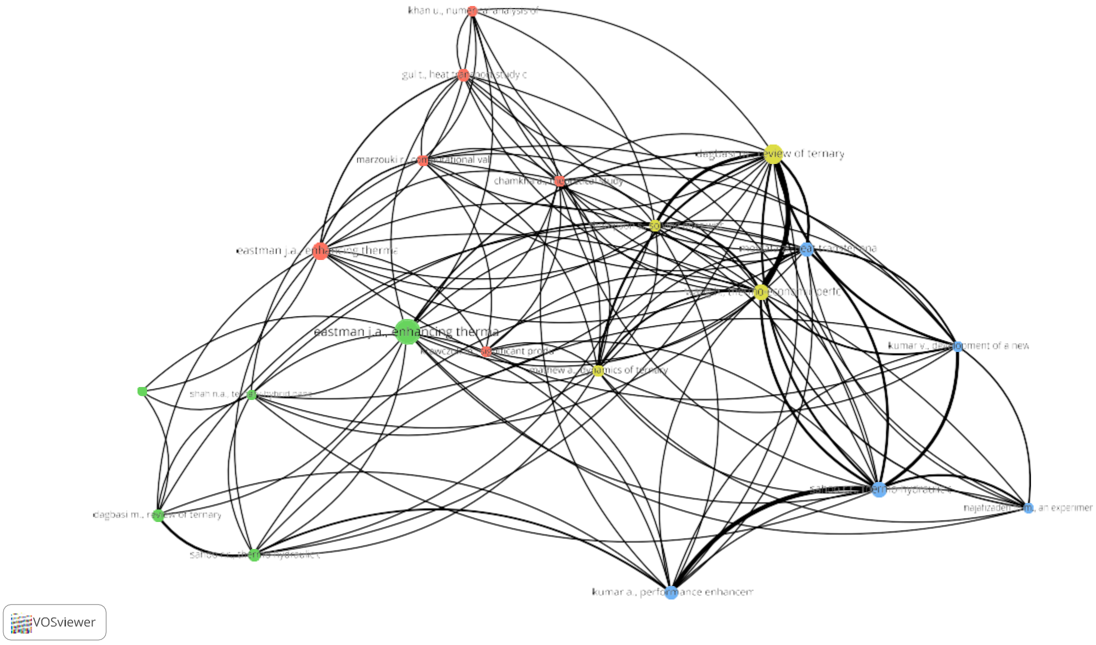

Figure 4: VOSviewer co-citation network visualization of the reference structure in ternary hybrid nano uid research.

Country Level Research Output and Collaboration

The national distribution of ternary hybrid nanofluid research appears in Table 3. It reveals the dominance of a relatively small group of countries with established strengths in thermal sciences and computational fluid dynamics. The geographic concentration is particularly pronounced across Asia and the Middle East. India leads the corpus by raw publication count. Saudi Arabia and Pakistan rank closely behind. Importantly, the leading countries also record high citation totals and substantial total link strength values. This indicates that their contributions are not merely voluminous. They are actively engaged with and built upon by the wider research community.

The country level coauthorship network in Figure 5 provides a relational perspective that complements these output statistics. Saudi Arabia and India emerge as the two most prominent nodes in the network. They are distinguished not only by their individual publication volumes but by the breadth and density of their international linkages. China, Pakistan, Turkey, Egypt, Malaysia, the United Arab Emirates, and South Korea also occupy well connected positions. Collectively these demonstrate that the collaborative backbone of this field spans a considerable portion of the globe. The geographic distribution of active participants makes clear that ternary hybrid nanofluid research is not a regionally concentrated endeavour. It draws contributors and collaborative partnerships from across Asia, the Middle East, Southeast Asia, and Europe.

Examining the network structure in greater detail, the strongest collaborative ties are concentrated within the Asia and Middle East corridor. Cross regional connections to European and Southeast Asian institutions are also present. From a practical standpoint, countries such as Saudi Arabia, India, and China stand out as natural entry points for researchers seeking international partnerships. This is due to their high connectivity and demonstrated capacity for sustained output in this domain. The coauthorship map thus serves two purposes. First, it offers a descriptive account of where the field's collaborative activity currently resides. Second, it acts as an empirical guide to where productive research networks are most likely to be found by those looking to engage with the global community working on ternary hybrid nanofluids.

Table 3

Top 10 most productive countries in ternary hybrid nano uid research.

Rank	Country	Documents	Citations	Total link strength
1	India	574	8947	857
2	Saudi Arabia	539	9923	1460
3	Pakistan	449	8155	1175
4	China	194	3388	451
5	Turkey	155	2602	602
6	Egypt	138	4310	439
7	Malaysia	125	1987	341
8	South Korea	90	1973	322
9	Taiwan	68	1399	290
10	Iran	65	1356	47

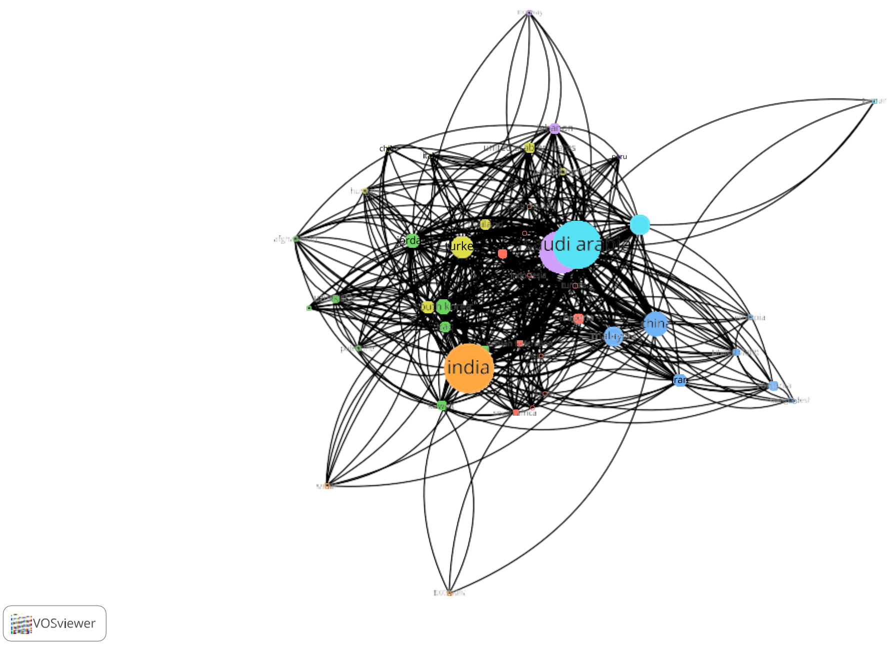

Figure 5: VOSviewer network visualization of country-level collaboration in ternary hybrid nano uid research.

Keyword Cooccurrence and Thematic Clusters

The keyword occurrence patterns from the dataset appear in Table 4. The three most frequent terms are *nanofluidics*, *hybrid nanofluid*, and *ternary hybrid nanofluid*. These reflect the central preoccupation of the field. It is concerned with advanced multi component fluid formulations and their thermophysical characteristics. Their dominance is unsurprising. The overwhelming majority of studies in this corpus are oriented toward the development, characterisation, or performance evaluation of nanofluid systems.

Beyond these primary descriptors, the frequency table reveals a consistent clustering of heat transfer and fluid dynamics terminology. Terms such as *heat transfer*, *magnetohydrodynamics*, *heat radiation*, and *nanoparticles* recur with notable regularity. They frequently appear in combination. This points to a substantial body of work concerned with fluid motion, convective and radiative heat transport, and the mechanisms through which dispersed nanoparticles modify bulk thermal behaviour. Material specific terms also appear. *Titanium dioxide* is a prominent example. This indicates that nanoparticle selection and its effect on thermophysical properties constitute a distinct and active area of investigation.

The full keyword cooccurrence network, visualised in Figure 6, reveals the cross cutting character of this research more completely. The primary terms occupy hub positions in the network. *Hybrid nanofluid*, *nanofluids*, and *ternary hybrid nanofluid* function as connective nodes. They link a thermal engineering core to a wide range of associated themes. On the applied side, these hubs connect to electronic cooling, biomedical engineering, cooling system design, and heat exchanger optimisation. On the theoretical side, linkages extend into porous media flow, non Newtonian fluid behaviour, and radiation driven transport processes. This structural arrangement confirms that the field is anchored in thermal improvement and flow analysis. Yet it is organised around multiple thematic branches rather than a single narrow trajectory.

Topics related to thermal enhancement, magnetic field effects, and flow behaviour predominate across the network. This underscores the field's defining research interests. At the same time, the keyword connections reveal its interdisciplinary reach. Keyword occurrence maps of this kind serve a function beyond description. They make visible both the densely populated regions of the literature and the comparatively sparse ones. This provides researchers with an empirical basis for identifying thematic gaps. It also helps them formulate research questions in areas where existing coverage remains limited.

Table 4

Top 10 most frequent keywords in ternary hybrid nano uid research.

Rank	Keyword	Occurrences	Total link strength
1	nano uidics	640	10950
2	hybrid nano uid	731	12706
3	nano uids	475	7638
4	ternary hybrid	514	8911
5	ternary hybrid nano uid	400	5844

6	heat transfer	243	4037
7	magnetohydrodynamics	222	4141
8	heat radiation	230	4296
9	nanoparticles	231	4091
10	titanium dioxide	169	3217

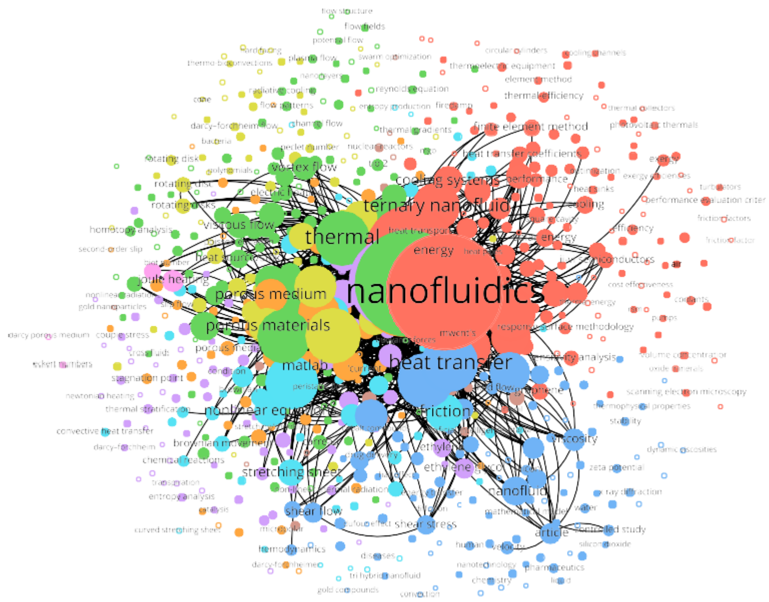

Figure 6: VOSviewer keyword co-occurrence map of ternary hybrid nano uid research.

Principal Funding Bodies and Sponsorship Patterns

An examination of the funding landscape reveals that financial support for this research is concentrated within a relatively small number of national agencies and university based research bodies. Geographically, Saudi Arabia, India, China, and Malaysia account for the majority of recorded funding activity.

Among institutional sponsors, King Khalid University emerges as the single most prominent funding body. Specifically, its Deanship of Scientific Research leads in recorded sponsorship. Several other Saudi universities also appear consistently among the top sponsors. These include King Saud University, Prince Sattam bin Abdulaziz University, and Northern Border University. The strong representation of Saudi institutions reflects the substantial investment that the Kingdom's higher education sector has directed toward applied thermal and fluid dynamics research in recent years.

National funding agencies complement this institutional support in meaningful ways. India's Department of Science and Technology and Ministry of Science and Technology rank among the most active governmental bodies. China's National Natural Science Foundation also figures prominently. These bodies actively finance work in this domain.

The coexistence of university level and national level sponsorship suggests that this research benefits from a layered funding structure. Targeted institutional grants operate alongside broader programmatic support from government science ministries. While the overall sponsorship landscape remains geographically concentrated, the diversity of funding types matters. Awards range from single institution research grants to large scale national programmes. This mix has contributed to the field's rapid expansion. It has also facilitated the kind of interdisciplinary collaboration that characterises the most productive research clusters. The top 10 institutions based on funding are presented in Table 5.

Table 5

Top 10 funding sources supporting ternary hybrid nano uid research.

Rank	Funding source	Documents
1	King Khalid University	86
2	Deanship of Scienti c Research, King Khalid University	72
3	King Saud University	49
4	Prince Sattam bin Abdulaziz University	33
5	Deanship of Scienti c Research, King Saud University	30
6	Northern Border University	27
7	Department of Science and Technology, Ministry of Science and Technology, India	25
8	Princess Nourah Bint Abdulrahman University	25
9	National Natural Science Foundation of China	20
10	Universiti Teknologi Malaysia	20

Emerging Research Directions and Future Trends

Recent contributions to ternary hybrid nanofluid research show a clear movement toward practical problems. Fundamental questions remain relevant. But the literature now places greater emphasis on issues such as advanced cooling, precise temperature control, and improved thermal management in high performance technologies. The underlying motivation is evident. Engineers seek to enhance the efficiency and operational stability of devices that generate substantial heat loads.

An expanding share of the literature addresses thermal configurations that are more complex than classical benchmark cases. Combined electric and radiative heating is one example. Phase change phenomena in which melting or solidification occurs alongside heat transport is another. Plasma flow environments also feature. Such studies aim to capture the behaviour of real systems in which several heat transfer mechanisms act simultaneously. These mechanisms cannot be separated in practice.

Methodological development is also becoming more visible. Data driven tools are gaining traction. Neural network based approaches in particular are being used to predict flow behaviour and support performance optimisation. At the same time, renewed attention is being given to the intrinsic properties of nanoparticles. Researchers are examining how size, geometry, and material composition affect thermal outcomes. This is especially relevant for industrial and biomedical applications. The requirements on fluid performance in these areas are often stringent. The field is increasingly characterised by the intersection of heat transfer, materials science, and computational design.

When considered as a whole, the evidence suggests that future research will advance along three closely related directions. Smarter cooling strategies represent the first. Improved modelling of coupled transport phenomena such as radiation and phase change represents the second. More deliberate nanoparticle design for specific engineering contexts represents the third. The field is moving beyond purely theoretical exploration. Its present trajectory is oriented toward practical solutions for advanced thermal technologies in manufacturing, energy systems, and biomedical devices.

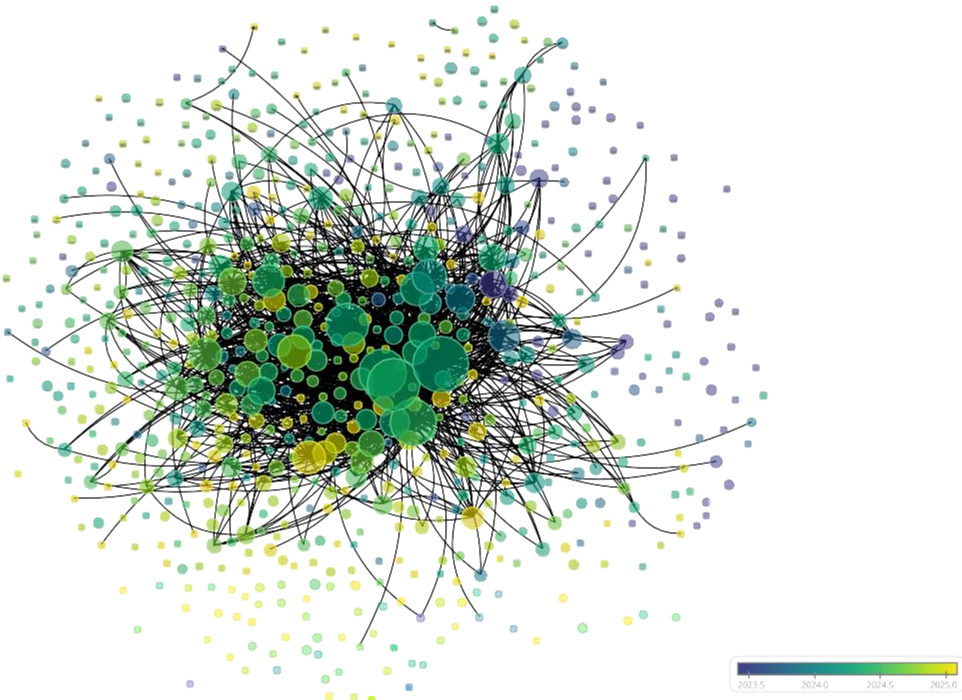

Figure 7: Temporal trend visualization of ternary hybrid nano uid research showing the evolution of emerging and future themes.

Conclusion

This study of hybrid nanofluid research gives us a clear picture of how this field is growing and what new areas it is moving into. The results show that ternary hybrid nanofluid research is growing quickly with a few important journals, authors, institutions and countries making big contributions. Most of the research is happening in places like Saudi Arabia, Malaysia, India, China and other universities that have a lot of support. This tells us that the support from universities and the priorities of countries play a role in helping this field move forward.

If we look at the topics that people are studying we can see that there is a shift from just looking at how heat moves to more practical uses. The next steps in hybrid nanofluid research might include things like cooling systems controlling temperature using neural networks to model things looking at how plasma flows studying how things melt and transfer heat and using radiation to heat things up. Future studies may also look at how nanoparticles with tailored shapes can be developed and how ternary hybrid nanofluids can be applied in both research and industry. All of these areas show that future research on nanofluids, hybrid and ternary hybrid nanofluids will focus on smart ways to manage heat combining different methods to optimize things and working across different fields like engineering and medicine.

The findings of this study on nanofluid research and nanoparticles are useful to researchers in several ways. First, the findings can help scholars identify suitable journals for publishing their work on ternary hybrid nanofluids and highlight key authors and institutions for possible collaboration. Second, researchers and collaborators may use information on countries and institutions when selecting universities for advanced study or short term research visits. Third, analyzing funding sources in this area can help researchers identify relevant sponsors and agencies that may support future grants and collaborative projects.

This review of ternary hybrid nanofluid research is a simple summary and also gives the guidance for future research directions in the field. It indicates both established areas, as well as new topics available for further investigation. The study provides useful insights to new researchers in the area that can be directly used to identify research gaps and opportunities. It also shows where the field is strong and where more work can have greater impact. In general, the analysis confirms that ternary hybrid nanofluids are a promising research area with significant potential for innovation in thermal engineering, numerical simulation and practical applications.

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