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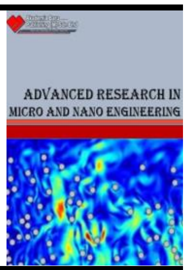

The Bibliometric Review on Convective Heat Transfer of Nanofluid

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ABSTRACT

Since convective heat transfer of nanofluids research has advanced significantly, it is helpful to have a brief overview of what has been done, who has been engaged, and how much they have contributed in order to choose our future course of action. Therefore, the objective of this study is to do a bibliometric analysis of the convective heat transfer of nanofluids. The reviewed articles were extracted using the advanced documents search function in *SCOPUS* database. The search keywords employed in this investigation encompass “convective heat transfer” and “nanofluids”. The first set of documents searched are sorted by article type and year, from 2002 to 2023. *VOSviewer* is then used to conduct the bibliometric analysis. Findings discovered that current and future research is moving towards investigating hybrid nanofluids flowing through microchannels and porous media, along with the influence of external factors such as pumping power.

1. Introduction

Heat transfer is the process in which energy in the form of heat moves from a higher temperature medium to a lower temperature medium. There are three types of heat transfer which are conduction, convection and radiation [1]. Convection is the transfer of thermal energy through the movement of fluids [2] and it is commonly used in heat exchangers where fluids flow over surfaces to exchange heat. Convection is considered one of the types of heat transfer that is very common in many industrial and engineering fields. Some examples of systems that use convective heat transfer are the cooling system in air conditioners and radiators, the heating system in steam generators and boilers, the climate control system in HVAC systems that either heat or cool the inside of a building, and the heat transfer in solar collectors that take in heat from the sun and add it to a fluid moving through the collector.

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In order to optimize the effectiveness of thermal energy transfer, a small amount of nanoparticles is introduced into conventional fluid making the thermal conductivity of the resulting nanofluid increase by a factor of two [3]. Nanoparticles not only improve thermal conductivity but also decrease temperature gradients and enhance heat transfer efficiency. That is why the primary objective of the usage of nanofluids in many engineering applications is to improve heat transfer in engineering devices [4]. When more than one type of nanoparticle is suspended in a base fluid, the resulting fluid is called a hybrid nanofluid [5]. The study on convective heat transfer of nanofluids and hybrid nanofluids has been studied widely by Elfiano *et al.*, Mahat *et al.*, Zokri *et al.*, and Abdullah *et al.*, [4, 6-9]. Studies and research on convective heat transfer have been expanding and developing since as early as the 19th century. Henry Dracy, Lord Rayleigh, Wilhelm Nusselt, and Ludwig Prandtl were among the pioneering scientists who made significant contributions to the advancement of convective heat transfer research. Researchers from several fields are drawn to study the convective heat transfer of nanofluids due to their individual interests in this subject area. Some of the primary fields that extensively study convective heat transfer include mechanical engineering, chemical engineering, nuclear engineering, fluid mechanics and mathematical sciences.

In mechanical, chemical, nuclear and many other engineering fields, engineers rely on experimental results to validate and refine their models. They do experiments and tests to make sure their design works and can handle the complicated needs of real-world uses. As in mathematical fields, the focus is on developing mathematical models, equations and analytical solutions to describe convective heat transfer. All in all, it can be said that engineers focus on practical applications while mathematicians focus on the development of theoretical models and analytical methods in their study. Despite their divergent interests, these fields of study often touch on each other, and researchers from different fields work together to solve difficult convective heat transfer problems. This is the reason why this field of study has continued to improve, advance and change throughout time and these improvements lead to new ideas in many industries and applications. Since convective heat transfer of nanofluids research has advanced significantly, therefore it is helpful to have a brief overview of what has been done, who has been engaged, and how much they have contributed in order to choose our future course of action.

As of October 2023, two bibliometric analyses of nanofluids have been conducted and published. The first study, conducted by Giwa *et al*., [10], is titled "Research trends in nanofluid and its applications: A bibliometric analysis". In this publication, the authors performed a bibliometric analysis specifically focusing on nanofluid and its various uses. The second study, authored by A. Svobodova-Sedlackova *et al.,* [11], is titled "A Bibliometric Analysis of Research and Development of Nanofluids." In this paper, the authors conducted a bibliometric analysis to examine the progress of research on nanofluids. Both bibliometric analyses concentrate on nanofluids in general, rather than particularly examining the convective heat transfer of nanofluids.

Therefore, the objective of this study is to review and examine scholarly literature on the convective heat transfer of nanofluids, which usually comes in the form of scientific papers and references. The method of reviewing chosen in this study is bibliometric analysis since this approach can help with identifying research trends, tracking research productivity, evaluating institutional performance and mapping collaboration networks. There is many software that can be used to conduct bibliometric analysis, several of them are Gephi, Leximancer and VOSviewer. VOSviewer is selected in this study since it excels at generating maps of collaboration and citation networks, enabling researchers to identify crucial authors, journals, and research groups. On the other hand, *Scopus* is selected to be used in this study as the search engine since it gives a broad range of publications.

2. Methodology
2.1 Bibliometric Approach

Bibliometric analysis is a review method that summarizes large quantities of bibliometric data to present the state of the intellectual structure and emerging trends of a research topic or field. In contrast to systematic literature reviews and thematic reviews, the bibliometric approach reviews a much broader scope and dataset that would be impracticable to review manually. Bibliometric analysis is divided into two distinct groups of methodologies, namely performance analysis and science mapping. Performance analysis primarily considers the contributions made by various research constituents, while science mapping mostly focuses on examining the linkages that exist between them [12].

Performance analysis is a common feature in many reviews, including those that do not specifically focus on scientific mapping. This is because it is customary for reviews to include an evaluation of the performance of various research elements such as authors, institutions, countries, and journals within the respective area. In contrast, scientific mapping is not a widely employed approach in other review approaches. Scientific mapping incorporates several techniques, including citation analysis, co-citation analysis, bibliographic coupling, co-word/co-occurrence analysis, and co-authorship analysis [13]. The integration of these techniques with network analysis is crucial for effectively illustrating the bibliometric organization and intellectual structure of the research field. The usage of all scientific mapping techniques is summarized in Table 1.

Table 1
Techniques for science mapping and their usage

	Technique	Usage
1	Citation analysis	Analyse the relationships among documents.
2	Co-citation analysis	Analyse the relationships among cited publications.
3	Bibliometric coupling	Analyse the relationships among citing publications.
4	Co-word/Co-occurrence analysis	To explore the existing or future relationships among topics in a research field.
5	Co-authorship analysis	Examine the social interactions or relationships among authors.

The process of bibliometric analysis consists of several steps which are determining the objectives, choosing the appropriate techniques, collecting data and running the bibliometric analysis and reporting the findings. Figure 1 summarizes the steps of bibliometric analysis conducted in this study.

2.2 Search String

Scopus's advanced document search function is utilized in step 3 to extract data. A query string of *Title-Abs-Key* is used to search for "convective heat transfer" and "nanofluids". Table 2 shows how the keywords are written in the search box.

Table 2
Search string in Scopus database

Keyword	Justification
“Convective* heat transfer”	To identify literature related to convective heat transfer
Nanofluids*	To identify literature related to nanofluids

The search initially returned 2139 documents, but after filtering for article type, the search results narrowed to 1693 articles published between 2002 and 2023.

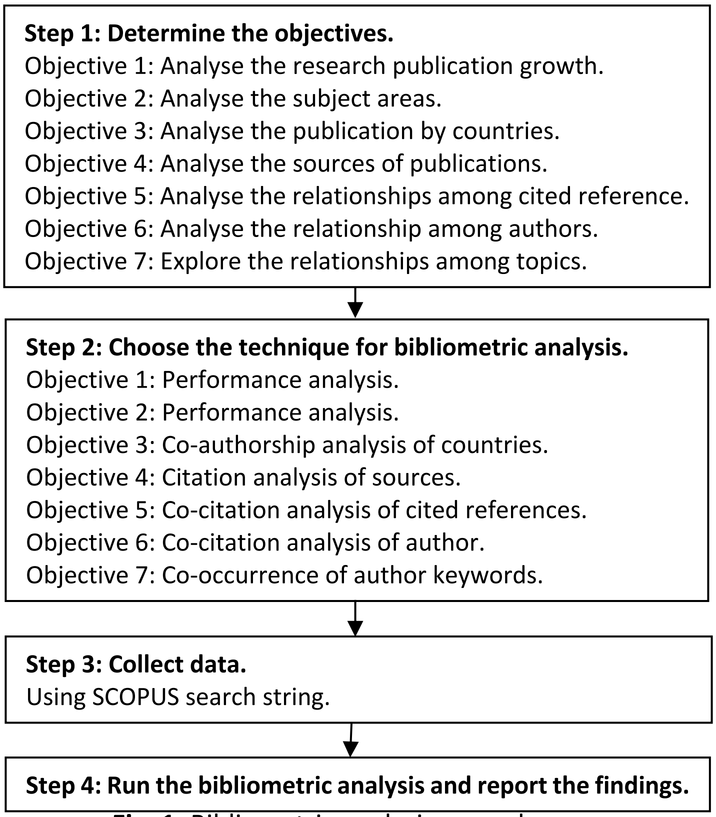

Fig. 1. Bibliometric analysis procedure

3. Results

In this section, all the results of performance analysis and scientific mapping analysis are presented.

3.1 Publication Growth

During the 21-year period, publications have continued even up to 2023, as shown in Table 3. The term nanofluid was first used by Choi and Eastman [14] in the year 1995 and the concept of nanofluid was then manifested by a series of research at Argonne National Laboratory [15]. Since then, research on nanofluids started to slowly grow and in the year 2009, there is a significant increase of 176.92% was recorded, with 36 publications compared to 13 publications in the previous year.

3.2 Subject Area

The convective heat transfer of nanofluids is a phenomenon that occurs in different systems, such as the flow of blood in human bodies, and the cooling or heating systems of machines and engines. Therefore, many researchers from various research and subject areas have studied this topic. It is identified that a total of 19 subject areas were involved in convective heat transfer of nanofluids research with engineering coming top with 950 papers (24.59%). Followed by physics and astronomy, chemical engineering and material science with 22.80%, 19.93% and 8.13% respectively. The summary of all subject areas with the total and percentage of publications are listed in Table 4.

Table 3
Publication growth

Year	Publication	% Publication	% Growth
2023	145	8.56	-7.64
2022	157	9.27	22.66
2021	128	7.56	-2.3
2020	131	7.74	-12
2019	149	8.80	-6
2018	158	9.33	-6
2017	168	9.92	6.33
2016	158	9.33	43.64
2015	110	6.50	20.88
2014	91	5.38	7.06
2013	85	5.02	32.81
2012	64	3.78	39.13
2011	46	2.72	58.62
2010	29	1.71	-19.44
2009	36	2.13	176.92
2008	13	0.77	8.33
2007	12	0.71	200
2006	4	0.24	33.33
2005	3	0.18	0
2004	3	0.18	200
2003	1	0.06	0
2002	1	0.06	

Table 4
Subject area

Subject area	Publication	% Publication
Engineering	950	24.59
Physics and Astronomy	881	22.80
Chemical Engineering	770	19.93
Materials Science	314	8.13
Energy	274	7.09
Chemistry	231	5.98
Mathematics	177	4.58
Computer Science	103	2.67
Environmental Science	40	1.04
Multidisciplinary	31	0.80
Biochemistry, Genetics and Molecular Biology	26	0.67
Dentistry	16	0.41
Earth and Planetary Sciences	15	0.39
Medicine	9	0.23
Pharmacology, Toxicology and Pharmaceutics	9	0.23
Business, Management and Accounting	8	0.21
Agricultural and Biological Sciences	5	0.13
Social Sciences	3	0.08
Economics, Econometrics and Finance	2	0.05

3.3 Publication by Countries

In this subsection, we summarize the analysis of countries with the most publications and institutions involved in funding and publishing research on the convective heat transfer of nanofluids. The co-authorship of the country analysis revealed that a total of 75 countries participated in publishing research on the convective heat transfer of nanofluids. However, only 47 countries met the criteria of having at least 5 documents and 0 citations in the bibliometric analysis. Under the science mapping technique, the number of published articles, citations, average citations, and total strength of co-authorship links with other countries are calculated for each country.

The top 20 countries with the highest number of published articles on convective heat transfer of nanofluids are listed in Table 5. Iran leads with 463 articles, followed by India, China, Malaysia, and Saudi Arabia with 353, 248, 141, and 130 articles, respectively. The strength of a link indicates how well different countries collaborate with each other on research projects. It is calculated by the number of collaborations that a specific country has engaged in with others. Even though Saudi Arabia has published fewer articles on convective heat transfer compared to Iran, India, China, and Malaysia, it is still recognized for its high level of collaboration in this field.

In terms of the total number of citations, the top five countries are Iran, India, the United States, China, and the United Kingdom with 24905, 11977, 11756, 10875, and 7,168 citations, respectively. Despite Singapore ranking 47th in the total number of published articles, it has the highest average citations of 149.2. This is because it received 746 citations in its only five articles.

Table 5
Publications by country

	Country	No. of articles	Citations	Total link strength	Average citations
1	Iran	463	24905	274	53.79
2	India	353	11977	155	33.93
3	China	248	10875	154	43.85
4	Malaysia	141	5912	189	41.93
5	Saudi Arabia	130	4141	288	31.85
6	United States	124	11756	138	94.81
7	Pakistan	113	4282	189	37.89
8	Turkey	94	4295	92	45.69
9	South Korea	54	3955	41	73.24
10	United Kingdom	52	7168	85	137.85
11	Iraq	51	1605	84	31.47
12	Egypt	39	707	70	18.13
13	Thailand	38	4034	41	106.16
14	Italy	35	2637	20	75.34
15	Canada	34	2412	42	70.94
16	Australia	33	1365	71	41.36
17	Romania	33	1591	45	48.21
18	Taiwan	32	1330	48	41.56
19	France	31	1204	29	38.84
20	South Africa	30	1083	54	36.10
	⋮	⋮	⋮	⋮	⋮
47	Singapore	5	746	5	149.20

Figure 2 shows a network map that displays the co-authorship of countries. The map classifies the countries into 11 clusters, which are represented by bubbles of different colors. The size of the bubbles corresponds to the number of published articles, and the lines connecting them indicate the strength of the links.

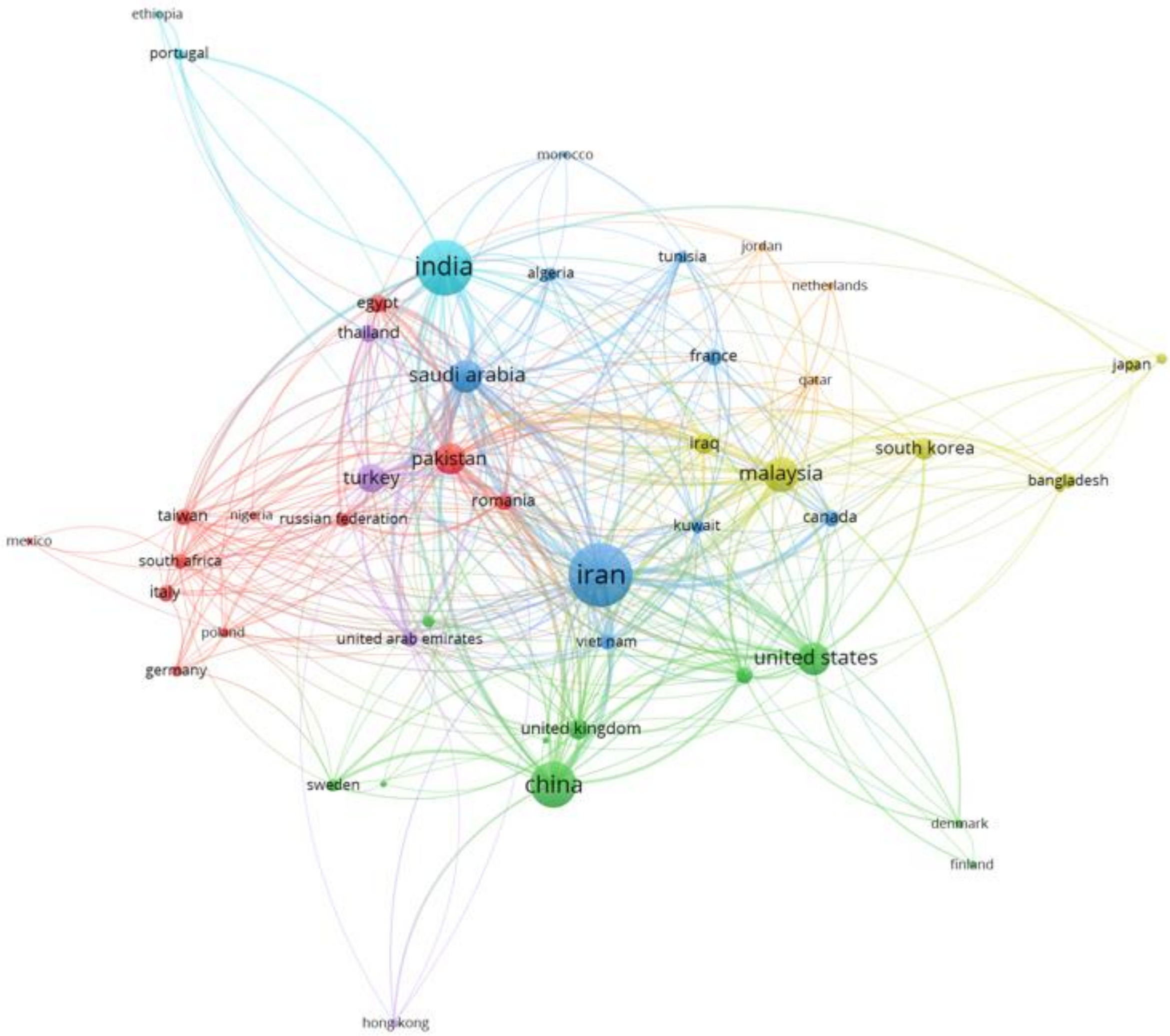

Fig. 2. Network diagram for co-authorship of country analysis

Many institutions have conducted extensive research on the convective heat transfer of nanofluids and published numerous papers on the topic. Universiti Malaya is the leading institution with the highest number of publications in this area, having produced 61 documents. Following closely behind are the Babol Noshirvani University of Technology and Ferdowsi University of Mashhad, with 53 and 49 publications respectively. Table 6 displays the top 40 institutions that have conducted research on convective heat transfer of nanofluids.

Table 7 on the other hand displays the top 20 institutions that have funded research in this area. Out of all the funding institutions, the National Natural Science Foundation of China has provided the highest amount of funding with 111 articles. This number is almost 4 times higher than the second-place institution, Universiti Malaya, which has only provided funding for 30 articles.

Table 6
Institutions involved in conducting research on convective heat transfer of nanofluids

	Institutions	No. of articles
1	Universiti Malaya	61
2	Babol Noshirvani University of Technology	53
3	Ferdowsi University of Mashhad	49
4	University of Tehran	47
5	Amirkabir University of Technology	38
6	Islamic Azad University	38
7	Kermanshah University of Technology	36
8	Anna University	30
9	Firat Üniversitesi	29
10	National Institute of Technology Tiruchirappalli	28
11	King Abdulaziz University	27
12	Isfahan University of Technology	27
13	Ton-Duc-Thang University	27
14	Prince Mohammad Bin Fahd University	27
15	Daneshgahe Elm va Sanat e Iran	25
16	Manisa Celâl Bayar Üniversitesi	25
17	Sharif University of Technology	25
18	King Mongkut's University of Technology Thonburi	23
19	Harbin Institute of Technology	22
20	King Khalid University	22
21	Ministry of Education of the People's Republic of China	21
22	Tomsk State University	20
23	Quaid-i-Azam University	20
24	Shahrood University of Technology	19
25	Research Institute of Petroleum Industry, Tehran	18
26	K. N. Toosi University of Technology	18
27	Universitatea Babeș-Bolyai	18
28	Islamic Azad University, Najafabad Branch	18
29	Universiti Kebangsaan Malaysia	17
30	Semnan University	17
31	Prince Sattam Bin Abdulaziz University	16
32	Universiti Teknologi Malaysia	15
33	Shiraz University	15
34	National University of Sciences and Technology Pakistan	15
35	University of Leeds	14
36	Shanghai Jiao Tong University	14
37	University of Guilan	14
38	Universiti Malaysia Pahang Al-Sultan Abdullah	14
39	Vellore Institute of Technology	13
40	University of Alaska Fairbanks	13

Table 7
Institutions involved in funding research on convective heat transfer of nanofluids

	Funder	No. of articles
1	National Natural Science Foundation of China	111
2	Universiti Malaya	30
3	Department of Science and Technology, Ministry of Science and Technology, India	27
4	Fundamental Research Funds for the Central Universities	22
5	Science and Engineering Research Board	17
6	National Research Foundation of Korea	15
7	Thailand Research Fund	14
8	Iran Nanotechnology Initiative Council	13
9	Ministry of Higher Education, Malaysia	12
10	Deanship of Scientific Research, King Faisal University	11
11	Ministry of Science and Technology, Taiwan	11
12	Engineering and Physical Sciences Research Council	10
13	King Mongkut's University of Technology Thonburi	10
14	National Science and Technology Development Agency	10
15	Department of Science and Technology, Government of Kerala	9
16	Ministry of Education and Science of the Russian Federation	9
17	Universiti Malaysia Pahang	8
18	University Grants Commission	8
19	Deanship of Scientific Research, King Saud University	7
20	European Commission	7

3.4 Sources of Publications

The 1693 reviewed articles are from 358 different journals. Using the technique of citation of sources, it is discovered that out of these 358 sources, 70 of them have at least 5 articles with 5 citations. Table 8 provides the 20 sources with the greatest number of articles. The highest of all is the International Journal of Heat and Mass Transfer with 117 articles and 17053 citations. It can be observed that the International Journal of Heat and Fluid Flow has fewer articles compared to Powder Technology and other sources. However, it has a higher average citation of 237.625, indicating that its papers were cited more.

3.5 Co-citation of Cited References

In the co-citation of cited references, two publications are linked when they both appear in the reference list of another publication. The analysis revealed that a total of 55629 documents were included in the research output, out of which 86 had a minimum of 15 citations. The cited references can be any type of document, it can be a book, article, or even conference report. The cumulative co-citation strength with other cited references is computed for each of the 86 references mentioned. Co-citation analysis is advantageous as it facilitates the identification of the most important publications. Table 9 provides information on the authors, year of publication, title, citations, and overall link strength of the top 15 cited references. The cited references that have the highest link strength are papers written by Pak and Cho [16] and Xuan and Li [17].

Pak and Cho, in their paper called "Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles" suggested that for improving heat transfer performance, it is advisable to choose particles with higher thermal conductivity and larger size when using dispersed fluids as a working medium. In the paper “Investigation on convective heat transfer and flow features of nanofluids”, Xuan and Li build an experiment to look into how convective heat transfer of nanofluids happens in a tube. They measured both the convective heat transfer coefficient and the friction factor of the sample nanofluids in a turbulent flow and as a result of their research, Xuan and Li proposed a new type of convective heat transfer correlation to correlate experimental data of heat transfer for nanofluids.

Table 8
Sources of publications

Source	No. of articles	Citations	Average Citations	H-Indexed	Quartiles
International Journal of Heat and Mass Transfer	117	17053	145.7521	236	Q1
International Communications in Heat and Mass Transfer	103	8201	79.62136	134	Q1
Applied Thermal Engineering	73	4961	67.9589	191	Q1
Experimental Thermal and Fluid Science	46	4936	107.3043	128	Q1
International Journal of Thermal Sciences	60	4861	81.01667	138	Q1
Journal of Heat Transfer	24	2895	120.625	137	Q2
Powder Technology	32	1989	62.15625	162	Q1
International Journal of Heat and Fluid Flow	8	1901	237.625	122	Q1
Journal Of Thermal Analysis and Calorimetry	84	1819	21.65476	111	Q1
Journal Of Molecular Liquids	29	1768	60.96552	150	Q1
Heat Transfer Engineering	20	1464	73.2	74	Q2
Energy Conversion and Management	19	1175	61.84211	232	Q1
Advanced Powder Technology	24	1098	45.75	89	Q1
Heat and Mass Transfer/Waerme-Und Stoffuebertragung	53	1035	19.5283	79	Q2
Renewable Energy	10	966	96.6	232	Q1
Case Studies in Thermal Engineering	32	928	29	59	Q1
Journal Of Magnetism and Magnetic Materials	8	858	107.25	187	Q2
International Journal of Numerical Methods for Heat and Fluid Flow	30	685	22.83333	64	Q1
International Journal of Mechanical Sciences	13	654	50.30769	131	Q1
Nanoscale Research Letters	9	654	72.66667	131	Q1

Table 9
Cited reference

	Author (year published)	Title	Citations	Total link strength
1	Patankar (1980) [18]	Numerical heat transfer and fluid flow	57	81
2	Maxwell (1881) [19]	A treatise on electricity and magnetism	52	140
3	Pak and Cho (1998) [16]	Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles	48	174
4	Wen and Ding (2004) [20]	Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions	46	160
5	Xuan and Li (2003) [17]	Investigation on convective heat transfer and flow features of nanofluids	40	174
6	Xuan and Li (2000) [21]	Heat transfer enhancement of nanofluids	37	104
7	Khanafer *et al.,* (2003) [22]	Buoyancy-driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids	31	92
8	Xuan and Roetzel (2000) [23]	Conceptions for heat transfer correlation of nanofluids	30	105
9	Coleman and Steel (1989) [24]	Experimental and uncertainty analysis for engineers	29	47
10	Oztop and Abu-Nada (2008) [25]	Numerical study of natural convection in partially heated rectangular enclosures filled with nanofluids	29	77

11	Choi and Eastman (1995) [14]	Enhancing thermal conductivity of fluids with nanoparticles	27	19
12	Eastman *et al.,* (2001) [26]	Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles	27	94
13	Brinkman (1952) [27]	The viscosity of concentrated suspensions and solutions	26	73
14	Buongiorno (2006) [28]	Convective transport in nanofluids	26	63
15	Drew and Passman (1999) [29]	Theory of multicomponent fluids	25	60

Figure 3 displays the network map of the co-citation analysis of cited references. The map consists of four clusters that have been classified and labelled based on the representative publication. The author's interpretation and understanding of the four clusters have been used to classify and label them.

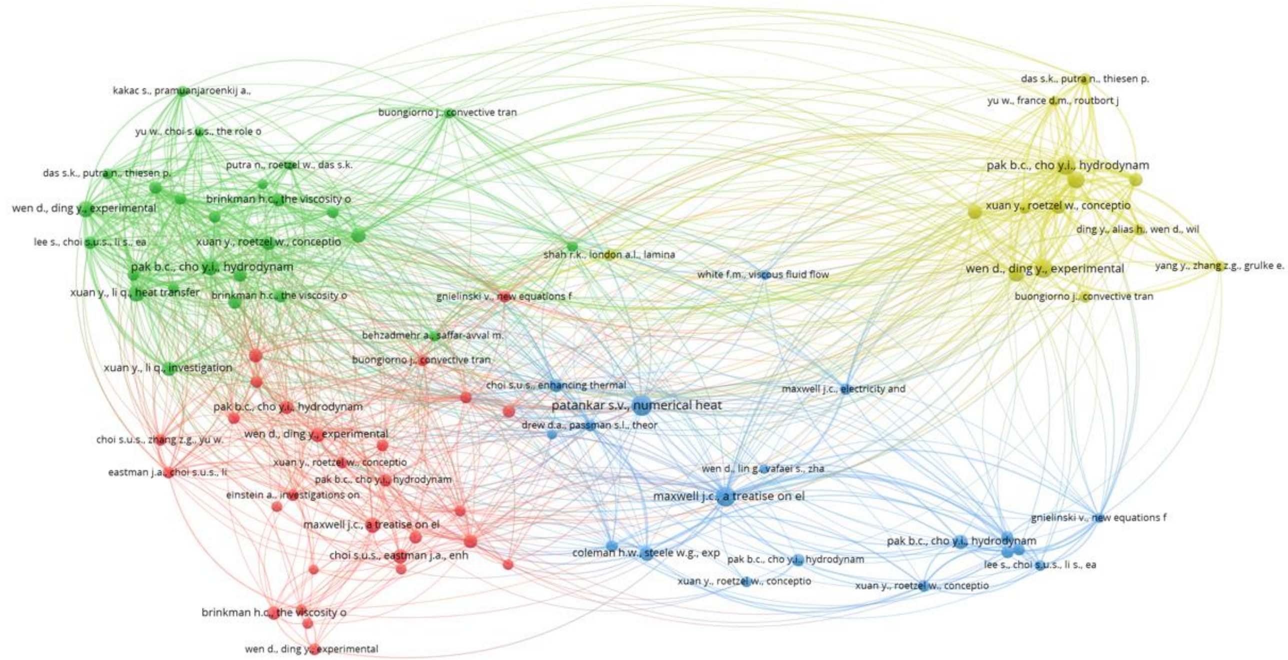

Fig. 3. Network diagram for co-citation of cited references analysis

References in cluster 1 mostly focused on the topic of laminar flow in convective heat transfer of nanofluids whereas those in cluster 2 were about heat transfer enhancement. Table 10 summarizes the cluster label, number of publications, and representative publications for each cluster.

Table 10
Co-citation of cited reference clusters

Cluster	Cluster label	No. of articles	Representative publication
1 (Red)	Laminar flow	28	Heat transfer properties of nanoparticle-in-fluid dispersions (nanofluids) in laminar flow by Yang *et al.,* [30]
2 (Green)	Heat transfer enhancement	25	Review of convective heat transfer enhancement with nanofluids by Kakac and Pramuanjaroenkij [31]
3 (Blue)	Heat transfer in pipe and channel flow	19	New equations for heat and mass transfer in turbulent pipe and channel flow by Gnielinski [32]
4 (Yellow)	Nanofluid thermal conductivity	14	The role of interfacial layers in the enhanced thermal conductivity of nanofluids: A renovated maxwell model by Yu and Choi [33]

3.6 Co-citation of Author

In order to analyze the relationships among cited authors, the minimum number of citations of an author is set to be 20. Out of the 36545, 1648 authors are cited at least 20 times but for this analysis, we just choose 1000 authors. The total length of the co-citation links with other authors is also calculated. The top 30 authors with the greatest number of citations are listed in Table 11 below.

Table 11
Cited author

Author	Citations	Total link strength
Choi S.U.S.	2100	166986
Sheikholeslami M.	1623	150709
Wongwises S.	1288	120211
Pop I.	1011	80728
Ding Y.	1011	86749
Ganji D.D.	997	107362
Xuan Y.	940	69308
Yu W.	935	81816
Eastman J.A.	900	70562
Oztop H.F.	891	74783
Chamkha A.J.	841	69750
Das S.K.	826	75996
Wen D.	784	65402
Li Q.	761	57877
Nguyen C.T.	740	64457
Buongiorno J.	702	57550
Afrand M.	671	71613
Toghraie D.	670	70239
Galanis N.	659	57694
Roetzel W.	656	51662
Saidur R.	655	58429
Roy G.	636	56608
Mahian O.	605	57988
Heris S.Z.	541	46908
Bahiraei M.	536	45807
Li S.	530	43339
Vafai K.	530	43516
Hayat T.	519	39599
Karimipour A.	514	56462
Pak B.C.	483	37538

Figure 4 shows the network map of the co-citation analysis of cited authors. The map is composed of three clusters that have been classified and labelled based on the groups of authors with similar preferences. The first cluster comprises authors who focus on measuring and enhancing thermal conductivity in nanofluids and the representative and most cited author in this cluster is Choi S.U.S. Table 12 summarizes the cluster label, number of articles, and representative author for each cluster.

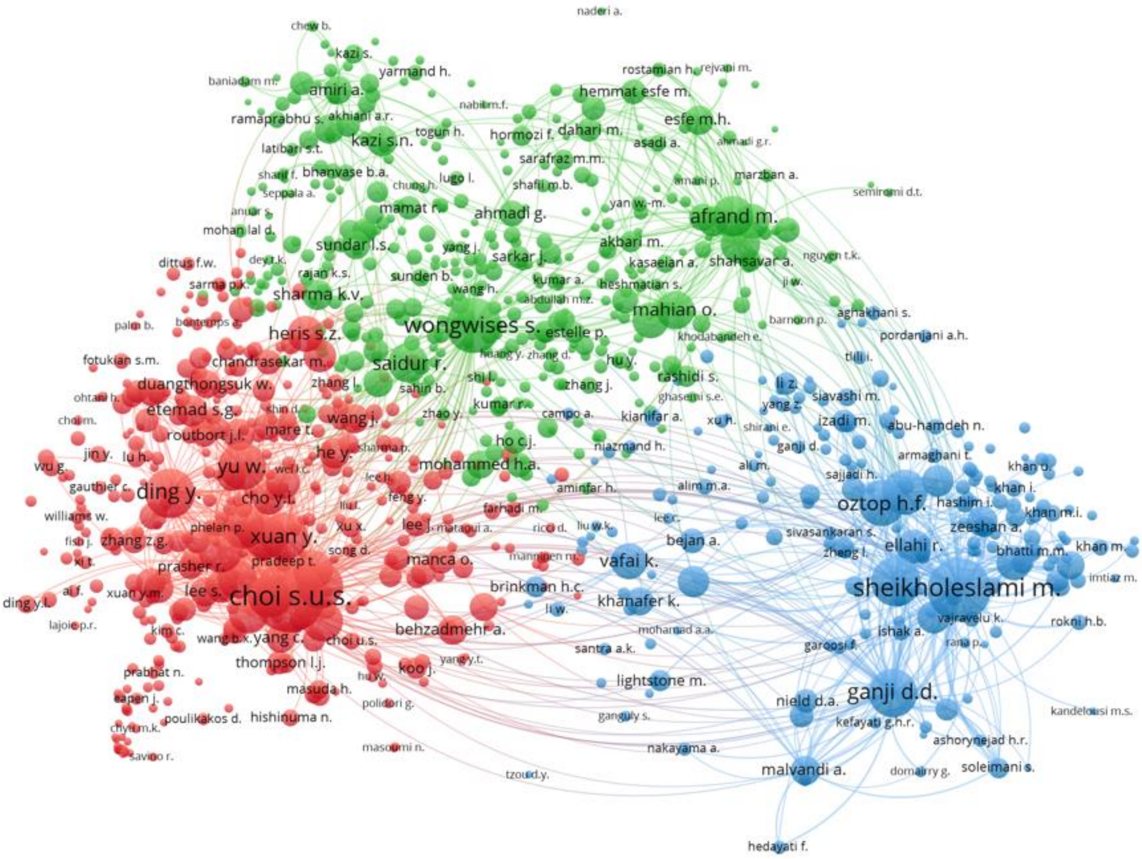

Fig. 4. Network diagram for co-citation of cited author

Cluster 2 contains 391 articles discussing nanofluids in solar energy, while cluster 3 contains 208 articles discussing magnetohydrodynamics effects in either ferrofluid or nanofluid flow. The representative authors for cluster 2 and 3 are Wongwises S. and Sheikholeslami M. respectively.

Table 12
Co-citation of cited author clusters

Cluster	Cluster label	No. of articles	Representative author
1 (Red)	Measuring and enhancing thermal conductivity in nanofluids	401	Choi S.U. S
2 (Green)	Nanofluids in solar energy	391	Wongwises S.
3 (Blue)	Magnetohydrodynamics effects in ferrofluid or nanofluid flow	208	Sheikholeslami M.

3.7 Co-occurrence of Author Keywords

For co-occurrence analysis of author keywords, the minimum number of occurrences of a keyword is set at 15. So out of 2648 keywords, 60 keywords are at least 15 times mentioned. For each 60 keywords, the total strength of the co-occurrence links with other keywords is also calculated. The highest co-occurrence keywords are nanofluid and nanofluids (993), heat transfer

(247) and convective heat transfer (226). Table 13 summarizes the top 20 co-occurred keywords with their number of occurrences and total link strength.

Table 13
Co-occurrence of author keywords

	Keyword	Occurrences	Total link strength
1	Nanofluid	580	1351
2	Nanofluids	413	923
3	Heat Transfer	247	625
4	Convective Heat Transfer	226	551
5	Heat Transfer Enhancement	139	324
6	Pressure Drop	108	330
7	Nusselt Number	107	286
8	Natural Convection	103	240
9	Laminar Flow	102	295
10	Thermal Conductivity	95	274
11	Heat Transfer Coefficient	94	232
12	Forced Convection	86	230
13	Magnetic Field	77	198
14	Friction Factor	73	225
15	Entropy Generation	64	173
16	Nanoparticles	64	184
17	Convective Heat Transfer Coefficient	62	124
18	Turbulent Flow	57	158
19	Mixed Convection	55	117
20	Hybrid Nanofluid	52	127

Figure 5 displays the network diagram illustrating the co-occurrence of keyword analysis. The map generates five clusters and is categorized and annotated according to the author's inductive interpretation of the words that appear. The clusters exhibit a high degree of relatedness and are partially integrated.

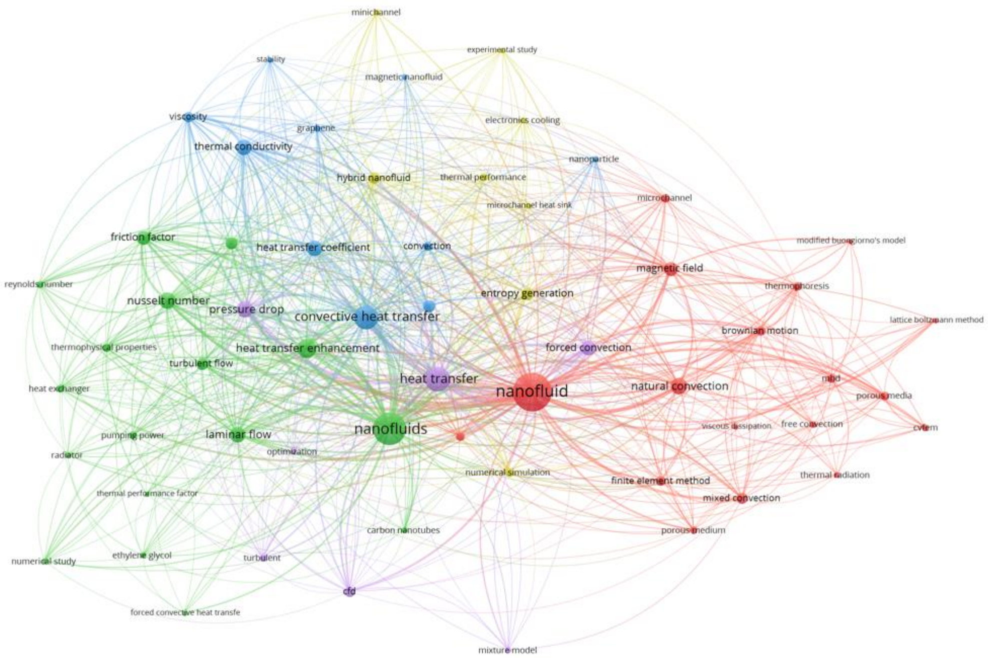

Fig. 5. Network diagram for co-occurrence of author keywords

There are 18 articles in the first red cluster that talk about the convective heat transfer of nanofluid embedded in porous media. These articles are related to the term "porous media." The second group has 17 articles that talk about extra force in forced convective heat transfer. Pumping power is the main keyword in this cluster. Table 14 provides a summary of the remaining clusters.

Table 14
Co-occurrence of author keywords cluster

Cluster	Cluster label	No. of articles	Representative author keywords
1 (Red)	Convective heat transfer of nanofluid embedded in porous media.	18	Porous media
2 (Green)	Extra force in forced convective heat transfer.	17	Pumping power
3 (Blue)	Parameters involved in convective heat transfer.	10	Heat transfer coefficient
4 (Yellow)	Convective heat transfer of hybrid nanofluid in microchannel and mini channel.	8	Hybrid nanofluid
5 (Purple)	The models involved in convective heat transfer.	7	Mixture model

4. Discussion

Deriving from the bibliometric analysis, a summarization of all findings is discussed here.

- Regional Contribution
  Researchers from Iran and India have published a significant number of articles on the convective heat transfer of nanofluids. The researchers from Iran have published 463 articles, while the researchers from India have published 353 articles. Despite the United States producing significantly fewer publications than India, the total number of citations for both countries is quite similar, with India having 11,977 citations and the United States having 11,756 citations. On the contrary, Singapore has the highest average citations, with a value of 149.2, due to its small number of published papers, which have been cited 746 times.

- Leading Institutions
  While Malaysia does not rank among the top three nations in terms of producing publications on convective heat transfer of nanofluids, the Universiti Malaya in Malaysia is the leading institution in terms of publishing extensively on this subject. Babol Noshirvani University of Technology and Ferdawsi University of Mashhad in Iran rank second and third, respectively.

- Financial Support
  Regarding financing for research on convective heat transfer of nanofluids, the Universiti Malaya in Malaysia ranks second, while the National Natural Science Foundation of China is the leading institution that has invested significantly in doing such research. The Department of Science and Technology, under the Ministry of Science and Technology in India, is third on the list.

- Prominent Journals
  The articles chosen for this review are published in a total of 358 scholarly publications. The International Journal of Heat and Mass Transfer is the leading publisher of research on convective heat transfer of nanofluids, with a total of 117 articles. The articles published in this journal have had the greatest number of citations, with a total of 17,053. Additionally, this journal has a high impact since it is categorized in Quartile 1 journal.

- Most Cited Reference
  As for the most cited reference, a book titled "Numerical Heat Transfer and Fluid Flow" written by Patankar S.V. and published in the year 1980 is listed in the reference of 57 reviewed articles. The second most cited document is also a book titled "A Treatise on Electricity and Magnetism" by Maxwell J.C. and this book was published in 1881.

- Citation Leaders
  As for the most cited author, Choi S.U.S is on top since his works were cited 2100 times with a total link strength of 166986. Choi together with Eastman developed the phrase "nanofluids" in 1995 [9]; hence, it is understandable why his works have received the most citations. Second and third on the list are Sheikholeslami and Wongwises with 1623 and 1288 citations respectively. Sheikholeslami and Wongwises are both researchers and academics specializing in the subject of mechanical engineering, specifically in the domain of thermal and fluid sciences.

- Research Themes
  Based on clusters formed by network mapping of co-occurrence of author keywords analysis, it is identified that the reviewed articles were focusing on porous media, pumping power, hybrid nanofluids, heat transfer coefficients and mixture model.

5. Conclusion

This paper presents a bibliometric review on convective heat transfer of nanofluids. Based on the five bibliometric analyses, the past, present and future research directions are summarized. Whether the convective heat transfer involves heating or cooling which are both equally significant, it has been discovered that research on convective heat transfer of nanofluids is undertaken by multidisciplinary researchers. Current and future research is moving towards investigating hybrid nanofluids flowing through microchannels and porous media, along with the influence of external factors such as pumping power.

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