

# A minimal bibliometric analysis review on the development of hybrid nanofluids

Kho Yap Bing and Rahimah Jusoh\*

Centre for Mathematical Sciences, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebu Persiaran Tun Khalil Yaakob, 26300 Kuantan, Pahang, Malaysia

**ABSTRACT** - The term "hybrid nanofluids" has emerged relatively recently, showcasing significant promise in elevating thermal conductivity while addressing the limitations of mono nanofluids. As of 2023, an extensive body of work, comprising over a thousand published articles on hybrid nanofluids, is accessible in renowned, high-impact-factor journals globally. To provide a comprehensive overview of this research field, this paper employs a bibliometric approach. Data pertaining to publications in the domain of hybrid nanofluids was collected from the Science Direct database, covering the years 2021 to 2023. The search was initiated by employing the query "hybrid nanofluid" in the title, abstract, and keyword search fields, followed by meticulous filtration to precisely extract pertinent articles. Additionally, this study employs VOSviewer software to interpret and analyse aspects such as co-authorship among countries and affiliations, publication citations, and co-occurrence of authors, offering a holistic understanding of the research landscape in hybrid nanofluids.

## ARTICLE HISTORY

Received : 05/04/2023  
Revised : 25/04/2023  
Accepted : 12/05/2023  
Published : 30/09/2023

## KEYWORDS

*Bibliometric analysis*  
*Hybrid nanofluids*

## 1. INTRODUCTION

Traditionally, base fluids such as water, ethylene glycol, and transformer oil have been used as conventional mediums to play a vital role in heat transfer, especially in electronic device systems, power plant cooling systems, machinery systems, and more. However, the outcomes often fall short of ideal expectations and can also lead to damage to machinery devices due to issues like overheating and inadequate heat dissipation. During the latter part of the 20th century, the concept of nanofluids was introduced and applied to address these limitations in heat transfer rates across a wide range of relevant applications where high thermal conductivity is imperative. The term "nanofluids" was first coined by Choi and Eastman [1] with the aim of innovating a new class of conventional heat transfer fluids by suspending metallic nanoparticles, known for their high thermal conductivities.

Additionally, building on the theory of thermally conductive slurries with nano-sized metallic particles put forth by Maxwell [2], research on nanofluid applications has expanded extensively. Das et al. [3] conducted a theoretical analysis of nanofluid properties and thermal conductivity potential. Further investigations into the applications and challenges of nanofluids were undertaken by Saidur et al. [4] and Wong and De Leon [5]. Undoubtedly, this topic has piqued the interest of numerous other researchers, who have explored various additional effects such as stretching/shrinking sheets, thermal radiation, chemical reactions, magnetic fields, heat dissipation, and more. Ghasemi and Hatami [6] delved into the influence of solar radiation on magnetohydrodynamic heat transfer in a two-dimensional stagnation-point flow of a nanofluid. They observed enhancements in nanofluid flow and heat transfer, particularly in velocity and temperature profiles, as the radiation parameter increased. This was presented in a numerical model where nanofluid flowed from an infinite vertical plate. The effect of MHD and thermal radiation of convective nanofluid heat transfer flow over an impulsively started vertical sheet have been investigated by Kumar et al. [7]. Mahabaleshwar et al. [8] studied the magnetohydrodynamic (MHD) flow of Newtonian nanofluids conducting electricity over a superlinear sheet. Their research verified that heat transfer decreases as the velocity profile improves with an increase in the magnetic parameter. Eswaramoorthi et al. [9] examined the consequences of various effects on convective nanofluid flow over a heated 3D plate. As a result, they found that the heat transfer gradient accelerates as the radiation parameter rises.

In spite of nanofluid shows better thermal conductivity than the base fluid, however, a new promising application have emerged by incorporation of two or more different metallic nanometer-sized particles in the fluids, namely hybrid nanofluids. The researchers tend to believe that the hybrid nanofluids could even manifest superior exceptional thermal behaviour with low concentration of coalescence from different type of nanoparticles; causes hybrid nanofluids indicate specific properties. Some latest reviews of applications on hybrid nanofluids with different aspects have been carried out by Dubey and Sharma [10], Kursus et al. [11], Modi et al. [12], Suneetha et al. [13]. Although that the hybrid nanofluids may owning greater potential but yet subjected to various limitations to fulfil the industrial scalability. In general, there is still a deficiency of consensus in the theoretical description defining the unique properties like exceptional thermal behaviour. Therefore, this will restrict the composition of hybrid nanofluids with the theoretical predictions and particular properties during the operative conditions. Consequently, the retrieved results may show low reproducibility and eventually causing hinder the promising nanotechnology in its industrial applications, as many uncertainties remains to

\*CORRESPONDING AUTHOR | Rahimah Jusoh | ✉ [rahimah@ump.edu.my](mailto:rahimah@ump.edu.my)

resolve. On the other hand, the growing interest in hybrid nanofluids is being attracted in the numerous of publications over the recent years. This fact implies that more various effects of study are being addressed, achieving a high technical and specialized level. Therefore, a mechanism is needed to overview the background, progress and limitations generally.

Bibliometrics analysis is considered as a statistical method that tracking the sources from scientific contents like books, articles, research publications, authors, regional places and so on. It is a tool to demonstrate the visualisation for the better understanding about research publication relationships. Mostly the researchers use bibliometrics analysis to study and review the past, present and future research development in a specific topic using related research publication appropriately. Furthermore, the scientific output was reported the annual overall quantity has reached around 3 million of publication. Meanwhile, bibliometrics has proved applicable and functional in respective scientific researches fields (Giwa et al. [14], Svobodova-Sedlackova et al. [15]). Recently, Sarkar et al. [16] performed the bibliometrics analysis of sustainable agriculture based from the Web of Science, Li et al. [17] studied the current status and future development on application of acupuncture in cardiopathy through bibliometrics analysis. The research of bibliometrics analysis on hybrid nanofluids as an advanced thermal fluid has been conducted by Giwa et al. [18] while Sarjana et al. [19] did the bibliometrics analysis on driving the renewable energy diversity by hybrid energy.

So far to our best information, there is no bibliometric analysis has been scrutinized in the field of hybrid nanofluids. On the other hands, only the nanotechnology and nanofluids have been determined. Hence, a simple bibliometrics analysis on hybrid nanofluids will be carried out in this paper work, the recent source of hybrid nanofluids publications from the year 2021 till 2023 is selected as the domain is then presented. Besides, it is easier to get through the relevant information by employing the bibliometrics analysis with identifying key performing players like study fields, affiliations, journal publications, regions and many others.

## 2. METHODOLOGY

The chosen data for this bibliometrics analysis were sourced from ScienceDirect Scopus database then employed and analysed by VOSviewer software. In order to obtain all the scientific journals or papers which are related to hybrid nanofluid, the “hybrid nanofluid” in the search query is employed, as well as the title, abstract and keywords. At the same time, there is the limitation by the Scopus database with the maximum of 1000 papers extractions. Hence, the appropriate range is defined as from 2021 to the present to limit the search and obtain data accurately. Relevant publications are selected and compiled into an Excel file, which is then imported into VOSviewer for network mapping visualization. By creating a map based on bibliographic data, the type and unit of analysis can be chosen according to the available options in the counting method. Once the threshold verification and document selection are completed, VOSviewer will generate the visualization of the results.

## 3. RESULTS AND DISCUSSION

The collections of total 220 relevant research journals were obtained then examine and interpret by bibliometrics analysis method. It is notice that there are 14 countries were divided into three clusters (according to the colour of red, blue and green) and involved in this bibliometric analysis as depicted in Figure 1. The cluster 1 (denoted as red colour) consists of seven countries which are China, Egypt, India, Morocco, Nigeria, Saudi Arabia and South Korea. The green colour of dot and line are represented for cluster 2 and there are five countries grouped together which are Pakistan, Taiwan, Thailand, Turkey and United Arab Emirates. Only two of the countries, Malaysia and Romania showed in cluster three. Another information can be found in Table 1 which demonstrated the ranking were affected by the total of link strength. The higher the link strength and cause the higher the ranking. Saudi Arab has the most of total link strength recorded as 8449 and place at top among the involved countries. In contrast, United Arab Emirates shows the least of the total link strength with score of 514 and place at the lowest rank.

The Figure 2 illustrated the interconnection coupling of authors and co-authors among these three years (2021-2023). They were divided into 14 clusters and the linking between the corporations of every author was clearly defined. The connection also illustrates the citation among the authors with each other; meanwhile, they are having the common mutual studies. For example, one of the authors extends the further study from another author’s paper publication. In short, it is understandably through the mapping visualization from every study aspect.

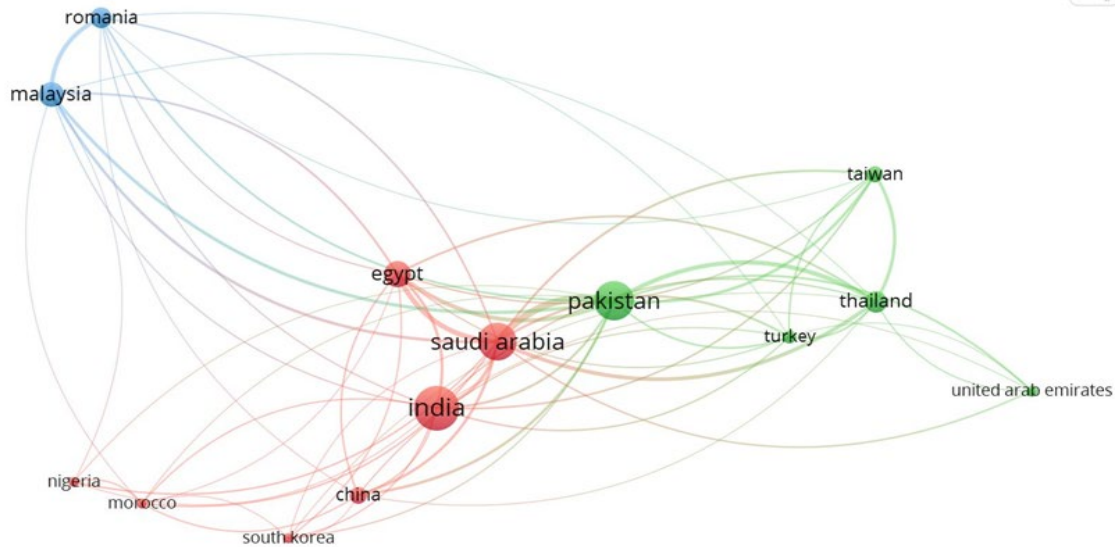


Figure 1. The involved countries of the main authors publishing in the field of hybrid nanofluid

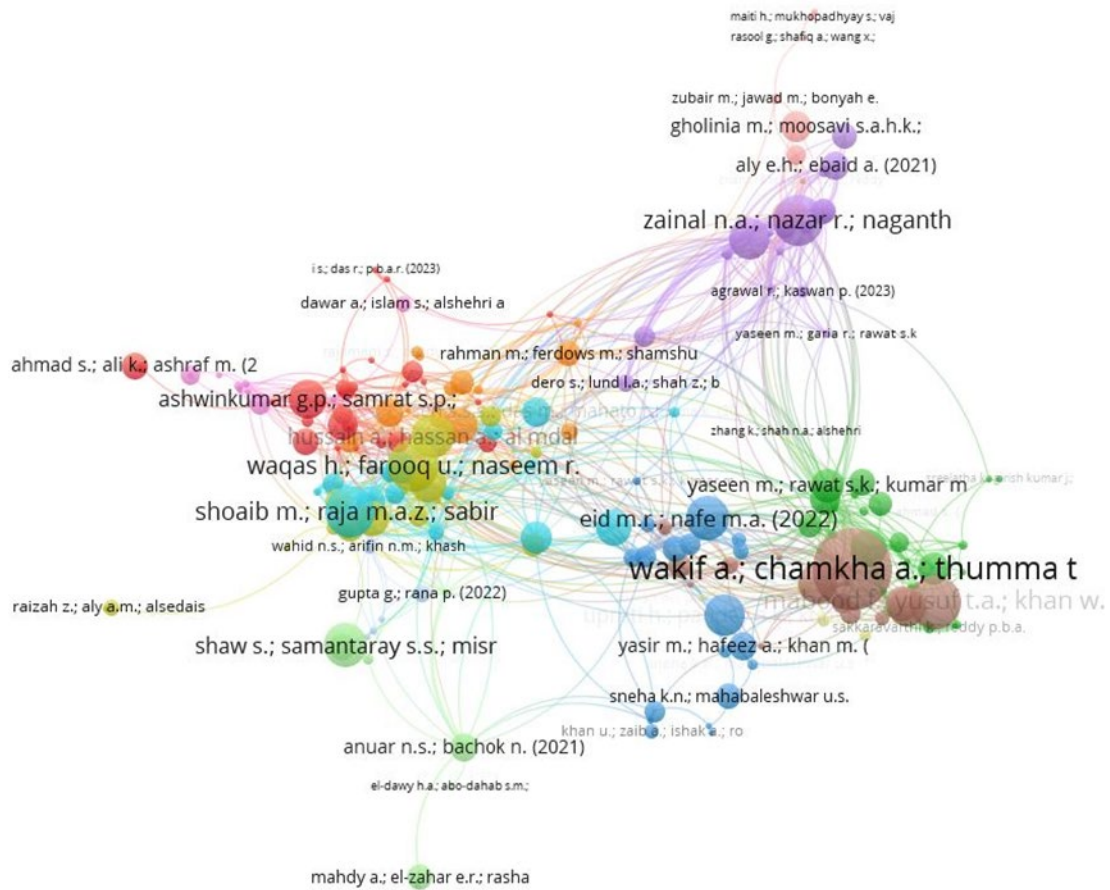


Figure 2. The relationship of main authors and co-authors publishing in the field of hybrid nanofluid

Table 1. The involved countries of the main authors publishing in the field of hybrid nanofluid

Country	Citations	Total Link Strength
Saudi Arabia	940	8449
Pakistan	843	8296
Egypt	302	4726
Malaysia	442	3993

Table 1. (cont.)

Country	Citations	Total Link Strength
India	1319	3555
Thailand	241	3336
Romania	324	2788
Taiwan	249	2193
China	109	1756
Turkey	76	1122
Morocco	228	1000
South Korea	25	708
Nigeria	311	588
United Arab Emirates	95	514

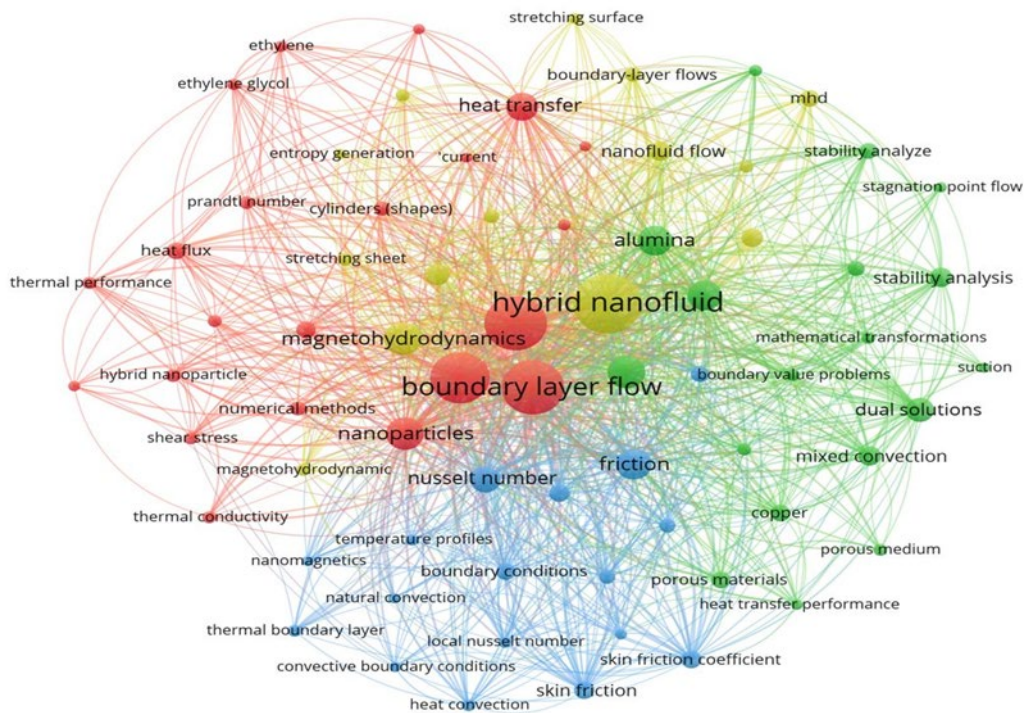


Figure 3. The relationship of main authors and co-authors publishing in the field of hybrid nanofluid

The physical configuration of mathematical formulation with the several parameters and various effects are divided into four clusters as depicted in Figure 3. The highest co-occurrence is “hybrid nanofluids” and “boundary layer flow”. The red colour represents the characteristics of heat transfer and the model of fluid. Most of the researchers will use the base fluid like ethylene (ethylene glycol), water and others to build up a medium with the combination of hybrid nanoparticles like alumina, silica, titania, copper and so on for the studies (Arif et al. [20]). Also, thermal conductivity, Prandtl number, thermal performance, heat flux, density is listed in the formulations of hybrid nanofluid and thermophysical traits respectively (Awan et al. [21]). The cluster of yellow colour defines as fluid flow environment. For instance, consider a hybrid nanofluid flow over a stretching/shrinking sheet, a vertical cone, or a horizontal cylinder. In this scenario, the thermal and momentum boundary layers (blue cluster) form between the fluid and the plate surface, allowing for an analysis of boundary layer thickness based on different parameters (green cluster). The green cluster pertains to mathematical problem-solving and parameters. For example, through mathematical transformations, partial differential equations are converted into ordinary differential equations. Typically, multiple solutions, known as dual solutions, can exist simultaneously. Stability analysis is then used to identify the most stable solution. The involved parameters usually are porous medium, stagnation point flow, suction and many others. Rehman et al. [22] had computed the smallest eigenvalue and determined the first solution was the stable solution for the problem of heat and mass transfer in radiative hybrid nanofluid with chemical reaction. The blue cluster denoted as boundary conditions, profiles and heat transfer rate. With the appropriate subjected boundary conditions, a finite solution then only can be obtained asymptotically. Nevertheless, the observation of the thickness of boundary layer from the velocity and temperature profiles is one of the ways to determine the influence of the parameter to the fluid. From the study of Alsaedi et al. [23], the higher the magnetic parameter cause the intensify of temperature of the hybrid nanofluid due to the heat produced

from resistive force by magnetic parameter. The skin friction coefficient and local Nusselt number also play the important rule in observing the shear stress and the behaviour of thermal conductivity of hybrid nanofluid flow respectively.

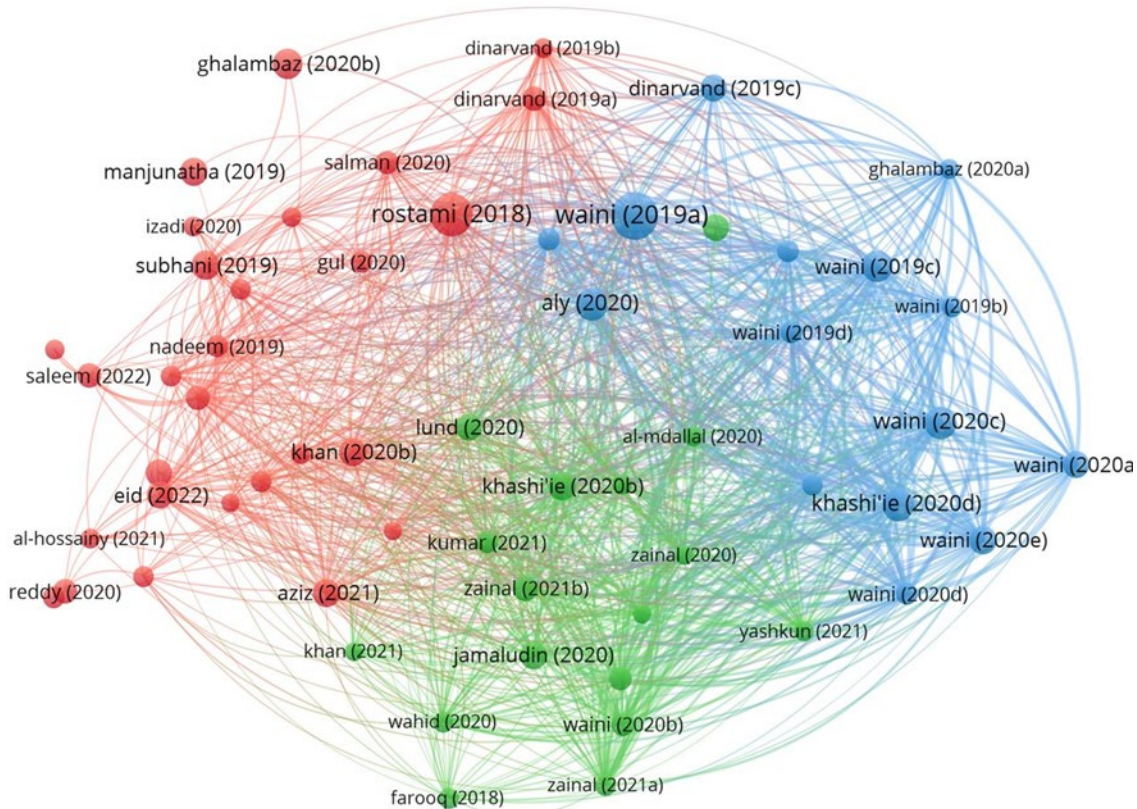


Figure 4. The relationship with the prominent authors in the field of hybrid nanofluid

Hereby with the Figure 4 presents the three clusters with the well-known authors in the study area of hybrid nanofluids. The authors located at the outer range are considered less interconnection with each other. Meanwhile, as closer to the centre of the mapping, the authors are more likely to cite the journals from each other. On the other hand, the authors most near to the centre which also represent as their researches may was extended work to other researchers so they have inter-relationship within each other's. As an example, in 2023, Waini et al. [24] examined the problem of homogeneous-heterogeneous reaction on the  $Al_2O_3$ -Cu hybrid nanofluid flow over a shrinking sheet. Their formulation model is considered as single phase, also called Tiwari and Das model. They concluded that the concentration gradient is intensified as enhancing the strength of homogeneous (bulk) and heterogeneous (surface). At the same time, this topic and related fields also will be considered in other researchers (Zafar et al. [25], Sheremet et al. [26], Muneeshwaran et al. [27]) as their investigation work but with different parameters and impacts, therefore, a co-occurrence of these researchers are assembled and accumulated when using the bibliometrics analysis method.

#### 4. CONCLUSIONS

A minimal review of bibliometric analysis on hybrid nanofluid has been presented in this work. According to the finding's information, the Asia countries showed the remarkable status in total link strength as well as in citations. Moreover, the physical configurations model, boundary conditions, parameters, boundary layer flow and other effects have been considered in hybrid nanofluids for further investigation to achieve a better understanding of hybrid nanofluids' unique thermal behaviour. Besides, many standard journals have been published from expert authors to examine the properties of hybrid nanofluids with various effects. Thus, the current research trend of hybrid nanofluid is considerably connected to one of the best-performing papers.

#### ACKNOWLEDGEMENTS

##### Institution(s)

All the authors would like to express their gratitude to Universiti Malaysia Pahang Al-Sultan Abdullah for the support/facilities.

##### Fund

The authors would like to thank the Universiti Malaysia Pahang Al-Sultan Abdullah for providing financial support under Internal Research Grant RDU223202.

**Individual Assistant**

NA

**AUTHOR CONTRIBUTIONS**

NA

**DECLARATION OF ORIGINALITY**

The authors declare no conflict of interest to report regarding this study conducted.

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