CHAPTER 1
THE EVOLUTION AND EMERGING TRENDS IN HYBRID NANOFLUID RESEARCH

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1.1 INTRODUCTION

The interest of researchers in nanofluid and hybrid nanofluid, however, extends beyond its varied applications; it's also a story of overcoming challenges and pushing the boundaries of scientific possibilities. Since Choi and Eastman's (1995) pioneering work, the global research community has been deeply engaged with the potential of this fluid. Their journey has been marked by persistent efforts to enhance the capabilities of nanofluid, particularly in thermal conductivity and heat transfer. This endeavour has not only showcased the resilience and adaptability of nanofluid under diverse conditions but has also highlighted its crucial role in advancing modern science and technology. Whether it's addressing the complexities of temperature fluctuations, responding to external factors like magnetic fields in magneto-hydrodynamic (MHD), or optimising thermal radiation processes, nanofluid has demonstrated an exceptional ability to offer innovative solutions, pushing the frontiers of what was once deemed unachievable. Hybrid nanofluid, which combines two distinct kinds of nanoparticles, is the result of this investigation. These particles not only improve the

thermal properties of traditional base fluid and mono nanofluid but also revolutionise heat transfer performance in various industries. The dynamic interplay of nanoparticles within the base fluid results in improved thermal conductivity and convective heat transfer.

Researchers are keenly exploring hybrid nanofluid due to their wide range of applications, including solar collectors, ventilation and air conditioning, photovoltaic thermal applications, refrigeration, heating, heat exchangers, coolants in machining and manufacturing, heat pipes, machine cutting, generator cooling, electronic cooling, the automotive industry, nuclear system cooling, electronic component thermal management, biomedical applications, and use in space, ships, and defense (Ali, 2020; Huminic & Huminic, 2018; Sarfraz et al., 2023). Hybrid nanofluid, as an advanced class of nanofluid, have shown improved heat transfer rates in various application areas. The demand for hybrid nanofluids has increased due to their enhanced heat transfer characteristics and stable properties (Alharbi et al., 2023; Wohld et al., 2022).

In recent years, the volume of scientific research has expanded substantially, making it increasingly challenging for researchers to stay abreast of relevant material in their fields. This situation underscores the need for quantitative bibliometric methods capable of managing vast data, identifying the underlying structure of topics, and highlighting significant works based on their impact. It is crucial, especially for researchers and PhD students, to develop skills for interpreting this surge of information (Zupic & Čater, 2015). Bibliometrics, originating from information science, uses quantitative analysis to evaluate scientific publications. It provides insights into historical, current, and potential future trends in specific fields.

By reviewing related research publications, bibliometrics not only tracks the development of new technologies but also supports research prioritisation, funding decisions, and recognition of scientific excellence. The accessibility of vast data and advanced analytical tools has made bibliometrics an invaluable resource for professionals at various levels of expertise, extending beyond its roots in information and library science (Adegoke et al., 2023; Mejia et al., 2021). Acknowledging the growing

interest and importance of nanofluid and hybrid nanofluid among researchers and scientists, this study conducts a bibliometric literature review. Utilising data from the web of science (WOS), the review covers articles from the past decade (2013–2022). The bibliometric analysis aims to identify existing gaps and chart new directions in nanofluid and hybrid nanofluid research. It also provides insights into key contributors, subject areas, institutions, publications, countries, funding agencies, and journals.

1.2 SAMPLE SELECTION PROCESS

For the bibliometric study at hand, data was extracted from the WOS database. This choice of database is driven by WOS's distinct advantages over other platforms like Scopus. Specifically, WOS is renowned for its meticulous curation of impactful and high-quality academic papers. Furthermore, it boasts exceptional search capabilities and citation analysis tools that empower comprehensive research endeavors. Such unique features and the platform's commitment to data reliability made WOS the preferred choice for this investigation (Ghalambaz et al., 2023). To collate publications pertinent to nanofluid research, a search query using terms "Nanofluid*" and "Hybrid nanofluid*" was executed, focusing on titles, abstracts, and keywords from the years 2013–2022. The data was further refined by selecting 'journal' as the document type, 'article' as the source type, and 'English' as the language. This data extraction took place on 27th October 2023.

1.3 DATA ANALYSIS

The initial search in our study resulted in a pool of 49,403 research papers. Applying filters based on publication year (from 2013–2022), the number was reduced to 38,856. Further refinement based on language restrictions narrowed the selection down to 38,748. A document type limitation, specifically to 'article', further decreased the count to 34,706. Finally, by excluding document types such as early access, proceeding