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Review Paper

Progress in the Developments of Heat Transfer, Nanoparticles in Fluid, and Automotive Radiators: Review and Computational Bibliometric Analysis

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Abstract

This research aims to determine (i) the development of the number of scientific publications in the field of particulate matter, (ii) the number of publications from each country that publish articles on heat transfer, nanoparticles, and automotive radiators (iii) articles with the highest number of citations (iii) visualization publication development map based on keywords. To achieve this goal, quantitative descriptive research was carried out using bibliometric analysis with the help of the publish or perish (PoP) application to collect data and VOSviewer to visualize related research topics. The article data taken is limited to 2018-2023. In addition, the terms heat transfer, nanoparticles, and automotive radiators are used as keywords in collecting article data using the pop application. Research on heat transfer, nanoparticles, and automotive radiators has increased in 2020 and India has become one of the countries that has contributed many publications on this topic. From the mapping results, research on heat transfer, nanoparticles, and automotive radiators is still being carried out frequently, especially in early 2020-2021. This research can help academics determine which problems to research and can be used as a reference for further research.

Keywords: Bibliometric; Mapping; Nanoparticle; Heat transfer; Automotive radiators

1. Introduction

Heat transfer, especially in the context of the use of nanoparticles, has become an increasingly important research topic in a variety of engineering applications, with a particular focus on automotive radiator applications. The heat transfer phenomenon is a key element in the efficiency and performance of heating and cooling systems, which has significant implications in various industries, including automotive [1].

Many reports regarding engineering and automotive have been well-developed. Some journals reported on this matter. In this analysis, the journals were focused on Automotive Experiences, Mechanical Engineering for Society and Industry, ASEAN Journal of Science and Engineering, and Indonesian Journal of Science and Engineering. This is because these journals are classified as the best journals in Indonesia in Engineering. Data was obtained from the Scopus database taken on 26 July 2024 with keywords "automotive" on Automotive Experiences, Mechanical Engineering for Society and Industry, ASEAN Journal of Science and Engineering, and Indonesian Journal of Science and Engineering.

Recent studies in combustion optimization and emission control have focused on achieving efficient and low-emission combustion processes. One prominent area is the development of Controlled Auto-Ignition (CAI) combustion strategies, which have shown promise in improving fuel efficiency while reducing emissions in internal combustion engines [2]. The potential for energy recovery from used motor oil through steam reforming has also been explored, suggesting a pathway to cleaner combustion by converting used oil into usable energy [3]. Furthermore, studies on knock and emission characteristics in lean spark ignition engines using gasoline, ethanol, and methanol blends have provided insights into stabilizing the combustion cycle and minimizing harmful emissions [4]. Studies on diesel fuel emulsions have revealed that varying degrees of blending in surfactant-free emulsions can improve engine efficiency and reduce emissions, offering a practical approach to optimizing diesel performance [5]. Furthermore, microcombustion in mesoscale burners is being investigated as a future energy source, highlighting the potential for compact and highly efficient combustion systems for next-generation vehicles [6].

The field of alternative fuels and advanced catalysts for sustainable energy has attracted considerable attention, particularly in the development of clean energy sources and reducing dependence on traditional fossil fuels. Fuel cell electric vehicles (FCEVs) have been proposed as a sustainable solution for heavy-duty transportation, with studies supporting the environmental and economic benefits of FCEVs over conventional diesel-powered trucks [7]. Research on the optimization of MCM-48 catalysts in biodiesel production is also progressing, as improved catalyst synthesis methods significantly improve the esterification process of alternative fuels such as nyamplung seed oil, contributing to the growth of the biodiesel industry [8]. Particle Swarm Optimization has also been applied to tune the duty cycle of oxyhydrogen generators, showing improved efficiency in hydrogen fuel applications [9]. Furthermore, honeycomb catalysts, particularly those supported by transition metals and coated with Al_2O_3, have been tested for exhaust gas oxidation, showing significant reductions in vehicle emissions [10].

Another area of focus is sustainable materials and environmentally friendly automotive components. The automotive industry is increasingly exploring environmentally friendly materials, such as non-asbestos brake pads made from bamboo powder, which provide an environmentally sustainable alternative while maintaining performance standards [11]. Additional research on brake pads made from agricultural waste, such as eggshells and banana peels, highlights their potential as an asbestos replacement, further encouraging sustainable practices in automotive manufacturing [12]. In parallel, research on the effect of cooling media on the mechanical properties of welded steels reveals that different cooling methods can have a significant impact on strength and durability, offering insights for the application of sustainable and high-performance materials in automotive structures [3].

In the field of vehicle safety, control, and comfort innovation, several studies aim to improve the driver and passenger experience through technological advancements. Infrared-based remote-controlled driving systems have been developed to assist individuals with lower-body impairments, offering a practical mobility solution that addresses accessibility challenges [13]. Research on motion sickness in automated vehicles provides further insights, particularly through the measurement of heart rate variability, which helps identify and mitigate conditions that cause passenger discomfort in a fully automated environment [14]. Additionally, deep learning models have been applied to predict and control vehicle trajectories during intersection turns, demonstrating advances in AI-driven vehicle navigation and safety [15].

Finally, studies on fuel performance and storage safety have become important in supporting the safe and efficient use of alternative fuels. An in-depth review of pure biodiesel (B100) analyzes its performance benefits and limitations, considering engine efficiency and environmental impacts [16]. In fuel storage, risk-based analysis of LPG storage tanks highlights the need for safety protocols, with a particular focus on leak prevention and response strategies, which are essential to prevent industrial accidents and ensure safe fuel storage [17].

Apart from the reviewed literature, currently, along with the development of technology, innovation in the use of nanoparticles in automotive radiators is becoming increasingly important in efforts to improve fuel efficiency and reduce environmental impacts. To assess these developments, bibliometric analysis is a powerful approach to identify the development, trends, and impact of research in a field of science [18]. By examining the existing literature and compiling bibliometric data, we can understand how research on this topic has developed over time, who has contributed, and where the research focus lies. Therefore, this paper aims to undergo a comprehensive bibliometric analysis that will provide in-depth insight into developments and publication trends related to heat transfer, the use of nanoparticles, and applications in automotive radiators.

We have conducted previous studies related to bibliometrics and have also been conducted by many previous researchers [19]–[35]. This method has proven to be accurate in mapping research patterns, limitations, and identifying new research gaps. Through this bibliometric analysis, we hope to reveal key patterns in research, identify the most influential publications, and highlight collaborations between researchers and research institutions that have played a role in developing knowledge in this domain. Additionally, it is hoped that this analysis will help in identifying future research directions and opportunities for further collaboration.

2. Methods

Bibliometric analysis and visualization methods were used in this research. Bibliometric visualization methods are used to present a structural picture of a particular research field. The bibliometric analysis used in this research is descriptive bibliometrics which describes the characteristics of a literary work. Bibliometric analysis is used for a variety of purposes, including identifying new trends in articles and journals. The sample in this study consisted of 49 publications indexed by Google Scholar using Publish or Perish software. The article data used are articles that have been published from 2018 to 2023. The publications collected come from various sources, namely journal articles. The keywords in this research are "heat transfer", "nanoparticles", and "automotive radiators". All article documents that were collected were used for visualization analysis with VOSviewer. Articles that are missing identity components (such as year of publication) will be completed manually using the Google Scholar website. After the data collection process is complete, the database containing a collection of articles and their identity components is saved in (*.csv) and (*.ris) formats. Data in this format (*.csv) was then imported into Microsoft Excel for further analysis. Likewise, the format (*.ris) is used for visualization analysis with VOSviewer. Detailed information regarding how to take data from bibliometrics is described elsewhere [36], [37].

By using the VOSviewer application, the collected data is then processed and visualized. VOSviewer can display three forms of visualization, each of which has its function and use. Performance analysis and mapping are two types of bibliometric analysis techniques. Performance analysis in the form of the number of publications per year, documents with the highest number of citations, institutions with the highest number of citations, journals with the highest number of citations, and use of the keyword shared author; then mapping in the form of Network Visualization, Overlay Visualization, and Density Visualization.

3. Results and Discussion

3.1. *Concept of Heat Transfer*

Heat transfer is the process of transferring thermal energy from an object or system with a high temperature to an object or system with a low temperature (see **Figure 1**) [38], [39]. There are three main summer transfer mechanisms:

3.1.1. *Conduction*

Conduction is the transfer of heat through a material without mass transfer of the material [40], [41]. Conduction occurs due to the movement of thermal energy (vibrations of atoms or molecules) which is transmitted from one atom or molecule to its neighboring atom or molecule. Good conducting materials, such as metals, have high thermal conductivity.

3.1.2. *Convection*

Convection is the transfer of heat through a mass movement of fluid (gas or liquid) [42], [43]. Convection occurs when a liquid or gas is heated, becomes less dense, rises, and is replaced by a cooler substance that falls. Convection is divided into natural convection and forced convection [44].

3.1.3. Radiation

Radiation is the transfer of heat through electromagnetic waves, such as infrared rays [45]. In carrying out heat transfer, radiation does not require a medium to propagate and can occur in a vacuum. All objects with temperatures above absolute zero (0 K) emit energy in the form of radiation [46].

3.2. Concept of Nanoparticles in Fluid

The concept of nanoparticles in fluids Refers to the use of particles with a nanometer size (1 to 100 nanometers) in a fluid. When nanoparticles are added to a fluid, be it a liquid or a gas, they can change the properties of the fluid. This phenomenon is known as "nanofluid." **Figure 2** shows an image of nanoparticles in a fluid.

In **Figure 2**, several factors influence the thermal conductivity of Nanoparticles in Fluid. Starting from nanoparticles to their stability in fluids, as well as other suspension properties, all these factors contribute, directly or indirectly, to variations in thermal conductivity. A brief description of the influence of each factor on thermal conductivity will be explained as follows [47].

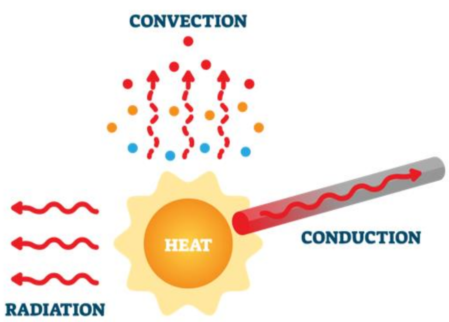

Figure 1. Concept of heat transfer

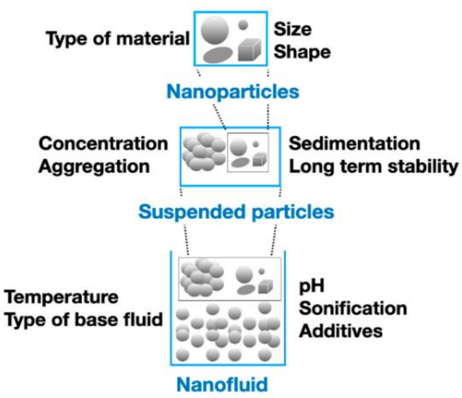

Figure 2. Concept of nanoparticles in fluid

3.2.1. Nanoparticles

Type of Material **-** The material type of the nanoparticle affects the thermal conductivity of the nanofluid [48]. Materials with high thermal conductivity, such as metals, can significantly increase the thermal conductivity of nanofluids.

Size Shape **-** The size and shape of the nanoparticles also matter. Particles with nanometer size and optimal shape can improve contact and heat transfer between particles, increasing thermal conductivity [49].

3.2.2. Suspended particles

Concentration Aggregation **-** The concentration of nanoparticles in the nanofluid can affect the thermal conductivity [50]. Particle aggregation can hinder heat movement and transfer, reducing thermal conductivity.

Sedimentation Long-term Stability **-** Sedimentation processes, in which particles tend to settle, can influence particle distribution and long-term stability of nanofluids.

3.2.3. Nanofluid

Temperature Type of Base Fluid **-** The temperature and type of base fluid play an important role. Temperature changes can affect the viscosity and thermal conductivity of nanofluids [51]. The type of base fluid also influences the interactions between the nanoparticles and the fluid.

pH Sonification Additives **-** The pH of the nanofluid, the sonication process (the use of sound waves for particle dispersion), and the addition of additives can affect the stability and performance of the nanofluid [52]. Appropriate pH and good particle dispersion can increase thermal conductivity.

3.3. Concept of Automotive Radiator

Automotive radiators are an important part of a vehicle's cooling system. Its main function is to remove excess heat generated by the engine during operation [53], [54]. The radiator ensures that the engine temperature remains within safe limits and prevents overheating [55]. The radiator will hold the coolant, cool the coolant, and distribute the coolant throughout the coolant circulation system lines. The air pump will send coolant to the engine block. The fluid flows around the cylinder and returns to the radiator through the thermostat. This coolant circulation takes place as long as the engine is running to prevent the engine temperature from becoming too high which can cause the drive components to overflow and melt and merge with other components in the engine combustion chamber.

Figure 3 shows the components of an automotive radiator. In **Figure 3**, an automotive radiator consists of 10 components, namely air flow, radiator cooling fan, radiator, upper radiator hose, water pump, lower radiator hose, coolant expansion tank, thermostat, and heater core [56]. The following is a more detailed explanation of automotive radiator components:

***Airflow* -** Airflow refers to the flow of air around the radiator which helps in the heat transfer process. This air can be caused by vehicle movement or assistance from the radiator fan.

***Radiator Cooling Fan* -** The radiator fan is installed behind the radiator core and functions to increase airflow through the radiator. This fan can rotate automatically when the coolant temperature is high to increase cooling efficiency.

***Radiator* -** The radiator is the main heat transfer core in the cooling system. Made of pipes and sheet metal, radiators remove heat from the coolant flowing through them.

***Upper Radiator Hose* -** The upper radiator hose is a flexible channel that connects the top of the radiator to the top of the engine. This allows the coolant that has been cooled in the radiator to return to the engine.

***Water Pump* -** A water pump is a pump that moves coolant through the cooling system. This helps maintain fluid flow so the cooling process can continue.

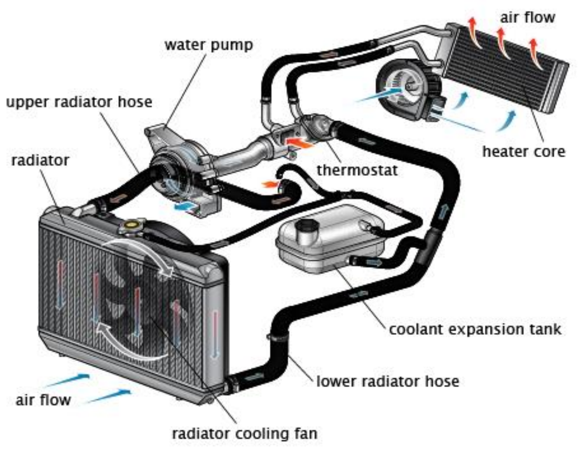

Figure 3. Concept of automotive radiator

***Lower Radiator Hose* -** The lower radiator hose is a channel that connects the bottom of the radiator to the bottom of the engine. This allows hot coolant from the engine to enter the radiator.

***Coolant Expansion Tank* -** A coolant expansion tank, also called an overflow tank or reservoir, is an additional storage place for coolant. This helps overcome changes in coolant volume due to temperature changes.

***Thermostat* -** The thermostat is a temperature control device located in the coolant path. Its function is to control fluid flow and ensure that the engine reaches optimal operating temperature.

***Heater Cores* -** The heater core is a small heat exchanger connected to the cooling system. It is used in vehicle heating systems to provide hot air into the vehicle cabin.

3.4. *What Happens in the Automotive Radiator when using Nanoparticles Fluid for Heat Transfer*

When using nanoparticle fluids in automotive radiators, several changes and benefits may occur in the cooling system. The following are some of the effects commonly associated with the use of nanoparticle fluids for heat transfer in automotive radiators:

***Increased Thermal Conductivity* -** Nanoparticles have a large surface area, so they can increase the thermal conductivity of the coolant [57]. In other words, the fluid becomes more efficient at conducting heat.

***Increased Cooling Capacity* -** By increasing the thermal conductivity, the cooling capacity of the liquid can also be increased [58]. This helps cool the engine more effectively, especially under high load or extreme temperature conditions.

***Operating Temperature Reduction* -** With better heat transfer capabilities, nanoparticle fluids can help maintain engine operating temperatures at lower levels, which can increase engine efficiency and lifespan [59].

***Corrosion Reduction* -** Several nanoparticle fluid formulations are designed to reduce corrosion on radiator components and other engine parts. Corrosion reduction can help increase the service life of the cooling system [60].

***Friction Reduction* -** Nanoparticles can reduce friction between fluid molecules, improving coolant flow and circulation [61]. Reducing friction can reduce the workload of the water pump and increase system efficiency.

Prevention of Sediment and Dirt Formation - Nanoparticle fluid can help prevent the formation of deposits and dirt in cooling systems. This can keep fluid circulation smooth and prevent blockage of the radiator or other channels.

Improved Cooling System Performance - Overall, the use of liquid nanoparticles aims to improve the performance of the cooling system, which can produce more stable and efficient temperatures in various operational environments.

However, it is important to remember that the effectiveness of nanoparticle fluids may vary depending on the formulation and conditions of use. Therefore, product selection and use must follow the manufacturer's recommendations and take into account the specific requirements of the vehicle or engine.

3.5. Bibliometric Analysis

3.5.1. Article Publication Trends from 2018 - 2023

Figure 4 shows the development of the number of publications on the topic under study over the last 5 years, namely from 2018 – 2023. Based on **Figure 1**, research on the topic under study forms a curve with a fluctuating shape, meaning that developments over the last 5 years have experienced ups and downs. At the beginning of 2018 – 2020, the number of publications on the topic under study increased significantly, namely from 4 publications in 2018 it increased to 7 publications in 2019, and experienced a peak increase in 2020 with the number of publications totaling 12 documents. In 2021 - 2023 the number of publications on the topics studied decreased, although in 2021-2022 the decrease was not too large compared to the previous year (a decrease of 2 articles). In 2021-2022 the number of publications on the topics studied will each be 10 documents and in 2023 6 documents.

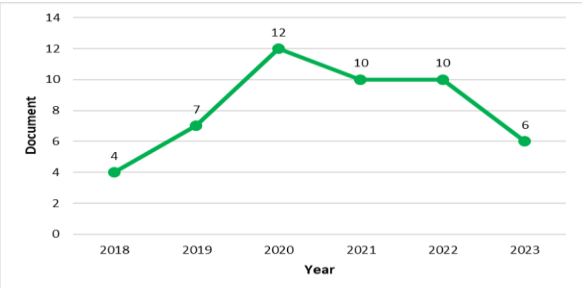

Figure 4. Development of publications from 2018-2023

3.5.2. Analysis of Citation

Apart from the development of publications per year, this research also examined articles that were widely cited by researchers. Citation functions to verify the data obtained so that our writing can be justified and have accountability. **Table 1** shows the ten articles with the most citations. Based on **Table 1**, Subhedar *et al.* [62] with their research entitled "Experimental investigation of heat transfer potential of Al2O3/Water-Mono Ethylene Glycol nanofluids as a car radiator coolant" received the highest number of citations over the last 5 years (2018-2023), namely 126 citations. With this number of citations, Subhedar *et al*. [62] is in first place as the author who has the article with the highest number of citations. Furthermore, there is research conducted by Contreras *et al.* [63] with the title "Experimental analysis of the thermohydraulic performance of graphene and silver nanofluids in automotive cooling systems" with a total of 120 citations. The numbers obtained by Contreras *et al.* [63] have a difference of 6 citations with the article entitled "Experimental investigation of heat transfer potential of Al2O3/Water-Mono Ethylene Glycol nanofluids as a car radiator coolant" which was researched by Subhedar *et al*. [62].

The citation of an article is important to support authenticity, prevent plagiarism, enable reproduction and verification, provide context and authority, support understanding, respect the contributions of others, and build a network of knowledge. Apart from that, when citing an article, it is also important for us to follow relevant citation guidelines (such as APA, MLA, Chicago, etc.). This is useful for ensuring that your citation is correct and consistent, and reduces the reliability and professionalism of the written work.

3.5.3. Analysis by Country

In this research, the countries that were most productive in publishing articles on the topics studied were also examined (see **Figure 5**). Based on **Figure 5**, India is one of the most productive countries in publishing articles related to the topic being researched compared to other countries such as Turkey, Pakistan, Nigeria, Malaysia, Maharashtra, Indonesia, Ethiopia, Egypt, China, Brazil, and Bangladesh. The number of publications produced by India from 2018-2023 was 22 documents. Meanwhile, Turkey produced 4 documents, Pakistan produced 4 documents, Nigeria produced 1 document, Malaysia produced 5 documents, Maharashtra produced 1 document, Indonesia produced 2 documents, Ethiopia produced 1 document, Egypt produced 1 document, China produced 3 documents, Brazil produced 4 documents, and Bangladesh produced 1 document. The number of documents produced may vary depending on the criteria for each research carried out.

3.5.4. *Visualization Analysis*

The visualization results using the VOSviewer application are shown in **Figure 6** (Network visualization) and **Figure 7** (Overlay visualization). Network visualization is represented by nodes and edges that are connected. The nodes represented by circles can be publications, journals, researchers, or keywords while edges indicate

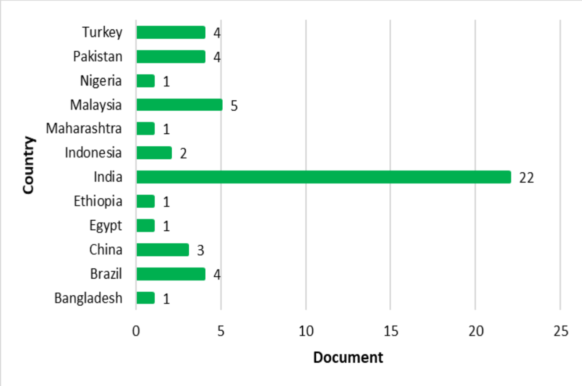

Figure 5. Countries with the highest number of publications

Table 1. Ten articles with the most citations

Cites	Authors	Title	Year	Ref.
126	Subhedar, D. G., Ramani, B. M., & Gupta, A.	Experimental investigation of heat transfer potential of Al_2O_3/Water-Mono Ethylene Glycol nanofluids as a car radiator coolant.	2018	[62]
120	Contreras, E. M. C., Oliveira, G. A., & Bandarra Filho, E. P.	Experimental analysis of the thermohydraulic performance of graphene and silver nanofluids in automotive cooling systems.	2019	[63]
117	Abbas, F., Ali, H. M., Shah, T. R., Babar, H., Janjua, M. M., Sajjad, U., & Amer, M.	Nanofluid: Potential evaluation in automotive radiator.	2020	[64]
72	Sahoo, R. R.	Thermo-hydraulic characteristics of radiator with various shape nanoparticle-based ternary hybrid nanofluid.	2020	[65]
70	Abbas, F., Ali, H. M., Shaban, M., Janjua, M. M., Shah, T. R., Doranehgard, M. H., Ahmadlouydarab, M., & Farukh, F.	Towards convective heat transfer optimization in aluminum tube automotive radiators: Potential assessment of novel Fe_2O_3-TiO_2/water hybrid nanofluid.	2021	[66]
69	Soylu, S. K., Atmaca, İ., Asiltürk, M., & Doğan, A.	Improving heat transfer performance of an automobile radiator using Cu and Ag doped TiO_2 based nanofluids.	2019	[67]
66	Kumar, A., & Subudhi, S.	Preparation, characterization and heat transfer analysis of nanofluids used for engine cooling.	2019	[68]
64	Elsaid, A. M.	Experimental study on the heat transfer performance and friction factor characteristics of Co3O4 and Al_2O_3 based H_2O/(CH_2OH) 2 nanofluids in a vehicle engine.	2019	[69]
57	Ramalingam, S., Dhairiyasamy, R., & Govindasamy, M.	Assessment of heat transfer characteristics and system physiognomies using hybrid nanofluids in an automotive radiator.	2020	[70]
38	Sahoo, R. R.	Heat transfer and second law characteristics of radiator with dissimilar shape nanoparticle-based ternary hybrid nanofluid.	2021	[71]

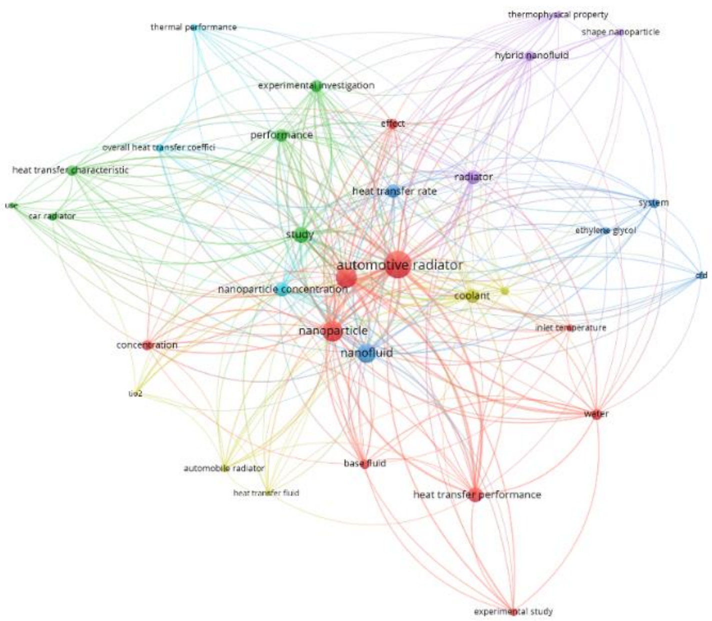

Figure 6. Network visualization

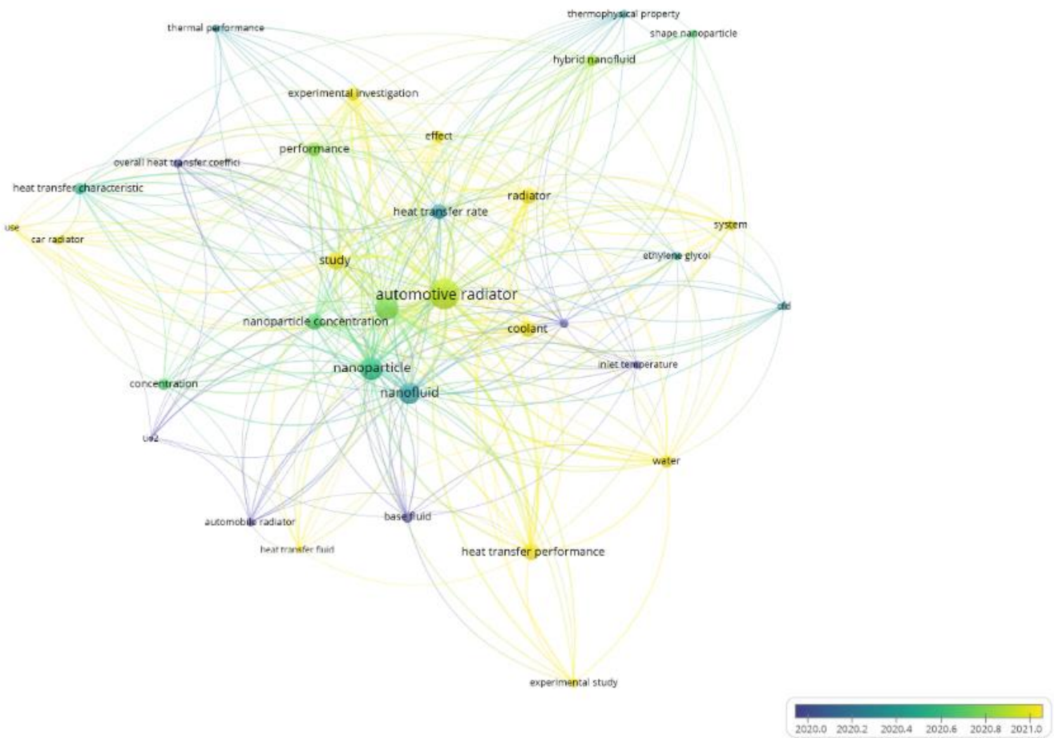

Figure 7. Overlay visualization

relationships between pairs of nodes. Apart from showing the relationship between pairs of nodes, edges also show the strength of that relationship. The strength indicated by the edge is represented by the distance. The closer the distance between one node and another node indicates the higher the relationship between the nodes. Mapping can be used to get a detailed picture of the structure of a network, while clustering is used to get insight or an overview of bibliometric groupings.

In Figure 5, each circle represents a frequently occurring term. These terms are taken from the title and abstract of an article. The size of the circle indicates the number of publications that are related to that term, both in the title and abstract of the article. The larger the size of the circle, the greater the number of articles that are relevant to that keyword or term. From the network visualization, 6 clusters were obtained. The following is a more detailed explanation of each cluster.

a. Cluster 1 marked in red has 10 items, namely automotive radiator, base fluid, concentration, effect, experimental study, heat transfer, heat transfer performance, inlet temperature, nanoparticles, and water.
b. Cluster 2 marked in green has 6 items, namely Car radiator, experimental investigation, heat transfer characteristic, performance, study, and use.
c. Cluster 3 marked in blue has 5 items, namely CFD, ethylene glycol, heat transfer rate, nanofluid, and system.
d. Cluster 4 marked in yellow has 5 items, namely Automobile radiator, coolant, heat transfer coefficient, heat transfer fluid, and TiO2.
e. Cluster 5 marked in purple has 4 items, namely Hybrid nanofluid, radiator, shape nanoparticle, and thermophysical property.
f. Cluster 6 marked with blue light has 3 items, namely Nanoparticle concentration, overall heat transfer coefficient, and thermal performance.

Apart from network visualization as described, this research also used another form of visualization, namely overlay visualization (Figure 6). Overlay visualization can be used to detect and identify the sophistication of a particular research subject. In the overlay visualization, the color of a node represents a keyword, while the color of the node indicates the year the article containing the keyword was published. The darker the color of the node, the longer the topic is discussed in the research. The overlay visualization in Figure 6 shows that topics related to nanoparticles are topics that are widely discussed in 2020, giving rise to great opportunities to become research topics now (2023).

4. Conclusion

Based on the results of the analysis, bibliometric studies are a powerful tool for tracking trends and developments in research on heat transfer, nanoparticles, and automotive radiators. This can provide valuable insights for researchers, practitioners, and decision-makers in this field. In addition, growth in the number of publications can be seen in this research. Research shows that 2020 is the peak year where the number of publications on topics used as keywords is widely used by researchers for research with a total of 12 publications. Then, the results of the analysis also show that there are opportunities for further research in the fields of heat transfer, nanoparticles, and automotive radiators. This research could focus on developing new technologies, reducing environmental impacts, and increasing efficiency in the automotive industry. This is supported by the visualization results obtained.

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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