CFD Letters

Involving Particle Technology in Computational Fluid Dynamics Research: A Bibliometric Analysis

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ARTICLE INFO	ABSTRACT
	This research was conducted to determine (i) the growth in the number of scientific publications in the field of particle technology in computational fluid dynamics (CFD), (ii) top citations based on the number of citations, publisher, and country, (iii) visualization of the most productive author, and (iv) publication development map based on keywords. This research method is a descriptive quantitative with bibliometric analysis using Publish or Perish software to harvest data and VOSviewer to visualize related research terms. Data was collected by searching using the Google Scholar database with the keywords "particle technology" and "Computational Fluid Dynamics" from 2019 to 2023. The results showed the growth of scientific publications in the field of particle technology in CFD. The most researched subjects in CFD are "technology," "CFD analysis," "fine particles," and "experimental validation," which are based on overlay and density visualization. The interrelationships between topics are grouped into four clusters with excellent network visualization. This research is expected to assist researchers in determining the topics to be studied and can also be a reference for further research.

1. Introduction

Computational fluid dynamics (CFD) is an engineering field that calculates flow fields and fields of related scalar variables, such as temperature and chemical species concentrations, in great detail for the domain of interest. The flow field calculations are carried out by solving discretized forms of the equations for mass, momentum, energy, and other variables. The result is a detailed flow field map that shows fluid velocities, temperatures, and species concentrations throughout the system. These findings can help better understand the system of interest. CFD results can be used to demonstrate how a piece of equipment works, how to troubleshoot problems, optimize performance, and design new equipment [1-3]. CFD simulations have been proposed for filtration applications such as filtration in fibrous media [4-6] and particulate filters [7], reactor modeling [8-10], colloids deposition in bidimensional [11], and three-dimensional porous media [12], to name a few. CFD relates to fluid flow. Several examples in the CFD research are presented in Table 1.

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Table 1
Several examples in the CFD research

No	Title	Objectives	Results	Ref.
1	Simulation analysis of thermal mixing characteristics of fluids flowing through a converging T-junction	The study aims to use CFD software called Ansys Fluent (ANSYS Inc.) to analyze the thermal mixing properties of hot and cold fluids at T junctions. A realizable k-turbulence model with a conventional wall function and energy equation model was utilized for simulation. As the solution approach, the SIMPLE scheme pressure-speed coupling method was applied. Temperature fluctuations were also affected by differences in inlet temperature and mass flow rate ratio.	Thermal mixing is influenced directly by the inlet temperature difference and the branch-to-main pipe flow rate ratio. The greater the temperature difference, the worse the thermal mixing performance. The flow rate of the branch to the main pipe increases thermal mixing. The degree of temperature change is evident within a short distance of the two inlets intersecting. The frequency of temperature fluctuation diminishes as the distance between the mixing outlet and the mixing chamber rises, and thermal mixing increases.	[13]
2	A validation study of the aerodynamic behaviour of a wind turbine: Three-dimensional rotational case	The research describes a validation study that employs low-cost computational resources to estimate the aerodynamic properties of the flow around the NREL phase VI wind turbine.	The results are consistent with the NREL UAE experimental data. The CFD model accurately captures all of the defining quantities. The shaft torque is well-predicted before the stall but under-forecasted during the stall. In the paper, the three-dimensional flow and stall are well recorded and presented. The results reveal that the attached flow exists in the pre-stall region. At a wind speed of 10 m/s, this separation appears around the blade root. When wind speed exceeds 10 m/s, the blade looks to enter a profound stall from root to tip.	[14]
3	Flow behaviour assessment of Smokey SAM rocket prototype	The study used a CFD technique to assess the aerodynamic performance of the designed Smokey Sam prototype rocket.	The turbulent properties of the flow are expressed using the K-omega (k- ω) model in this study. The real pressure distribution was compared to the exact pressure distribution of the traditional rocket material to determine the optimal rocket material for maintaining the best strength-to-weight ratio at high-speed trajectory operation. Several observations, such as ambient velocity and pressure, were incorporated into the modeling procedure. The flight is confirmed to be in stable mode because the obtained pitching moments are nearly zero at all tested speeds.	[15]
4	Application of polyhedral mesh for vortex formation study for simple single pump sump	The applicability of a polyhedral mesh structure to vortex generation research on a basic single sump pump model was examined in this work. The results were then compared to hexahedral and tetrahedral mesh systems and experimental data from previously published works.	The polyhedral mesh system performed admirably, matching the results of the hexahedral mesh system and the experimental data.	[16]

| 5 | Effect of cavities in suddenly expanded flow at supersonic Mach number | This research examined the effect of the Mach number on the basic pressure calculated using a numerical approach using CFD analysis, which considered the expansion rate and cavity aspect ratio. | The results show that the expansion level, expanded duct size, and passage area ratio all have an effect on the base pressure. The presence of voids influences bed pressure and is one of the most valuable strategies for lowering net resistance. Additional studies can be undertaken to determine the ideal cavity geometry for maximum bottom pressure. Furthermore, different cavity designs should be examined to achieve the greatest base pressure rise and fall. The hollow has no effect on the flow pattern of the channel. | [17] |

In general, many studies show that fluid flow depends on the viscosity of the fluid in which the viscosity characteristics are sufficient depending on several parameters, such as temperature, volume concentration, aggregation, particle shape, surfactant, and particle size. Turgut *et al.,* [18] conducted an experiment to measure the viscosity of TiO_2-water nanofluids, observing a decrease in viscosity values with increasing temperature. Sundar *et al.,* [19] prepared a review paper on viscosity, which confirmed the results of Turgut *et al.,* [18] in terms of temperature. Bahiraei *et al.,* [20] and Sundar *et al.,* [19] conducted experiments to interpret the effect of concentration on viscosity using Fe_3O_4–water (0.1–1%) and TiO_2-water (0–2%) nanofluids. They both concluded that the viscosity increases with increasing concentration. Aggregation also plays an important role in the viscosity of the nanofluid [21]. Gaganpreet *et al.,* [22] focused on fractal aggregates and interfacial layers around the nanoparticles to determine the rheology nanofluid behavior, which found that the enhancement was effective, causing a large increase in viscosity. In addition to aggregation, the viscosity of the nanofluid also depends on particle shape [23]. Timofeeva *et al.,* [23] recommended the use of nanoparticles with a spherical shape for lower viscosity values. The use of surfactants can be an effective way to achieve stable behavior of nanofluids [24]. Accordingly, the increase in viscosity may depend on the type of surfactant. The influence of the size of the dispersed nanoparticles on the viscosity is another important parameter.

Many studies have studied the effect of particles on fluid flow. However, no previous bibliometric reviews have been presented that report current research trends on the effects of the presence of technology particles in CFD research. Current studies on the use of bibliometrics have been well-documented in Table 2. Then, based on previous bibliometric research and our research on previous bibliometrics, as shown in Tables 2 and 3, here, we present a bibliometric review of the application of particle technology in CFD. The novelty of this work is to provide a bibliometric review highlighting keyword evolution, collaborations between authors, most cited articles, and top journal-published sources regarding particle technology and CFD.

Table 2
Previous studies on bibliometric analysis

No	Title	Topic Discussion	Ref.
1	Dental suction aerosol: Bibliometric analysis.	The distribution of bibliometrics maps and research trends using VOSviewer was used in this study to explain the evolution of dental aerosol suction.	[25]
2	A bibliometric analysis of Covid-19 researches using VOSViewer.	Using bibliometric analysis, this study examined the evolution of research during the Covid-19 era.	[26]
3	The latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: Literature review and bibliometric analysis	This study examined the literature on the benefits and drawbacks of pure biodiesel on engine performance.	[27]
4	A bibliometric analysis of management bioenergy research using VOSviewer application	This study examined research trends and developments in the field of bioenergy management.	[28]
5	Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis	Bibliometric analysis and VOSviewer were used in this study to examine the use of benzotriazole ionic salt liquid as a solvent for empty palm oil fruit bunches.	[29]
6	Biomass-based supercapacitors electrodes for electrical energy storage systems activated using chemical activation method: A literature review and bibliometric analysis.	The potential of biomass-based carbon as the electrode of a highly efficient supercapacitor to facilitate highly efficient current transport in energy storage systems was discussed.	[30]
7	Bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSViewer	This paper discussed the bibliometric analysis of nFs for medical science by combining mapping analysis with VOSviewer software.	[31]
8	Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021.	The purpose of this study was to discuss scientometric studies in the organizational progress and prospects of SA and its derivatives.	[32]
9	Correlation between process engineering and special needs from bibliometric analysis perspectives.	The integration of mapping analysis using the VOSviewer program was discussed in this study.	[33]
10	Bibliometric analysis for understanding the correlation between chemistry and special needs education using VOSviewer indexed by Google.	This study discussed the use of VOSviewer in conjunction with mapping analysis.	[34]
11	Computing bibliometric analysis with mapping visualization using VOSviewer on "pharmacy" and "special needs" research data in 2017-2021.	This study looked at mapping visualization in research with pharmaceutical topics and special needs over the next five years (2017-2021).	[35]
12	Nutritional research mapping for endurance sports: A bibliometric analysis.	This study examined research mapping in the field of endurance sports nutrition.	[36]
13	Bibliometric and visualized analysis of scientific publications on geotechnics fields.	Using the VOSviewer application, this study examined the evolution of research in Geotechnical Engineering through bibliometric distribution maps.	[37]
14	A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation.	This research examined the description of research developments in science education and engineering.	[38]
15	What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using VOSviewer indexed by Google Scholar?	The VOSviewer application is used to analyse "Special Needs of Chemical Engineering" in this study.	[39]
16	Counselling guidance in science education: Definition, literature review, and bibliometric analysis.	A literature review and bibliometric analysis are used in this study to discuss the topic of guidance and counselling in science education.	[40]

No	Title	Topic Discussion	Ref.
17	Phytochemical profile and biological activities of ethylacetate extract of peanut (Arachis hypogaea L.) stems: In-vitro and in-silico studies with bibliometric analysis.	In-vitro and in-silico chemical content and pharmacological activity of A.hypogaea stems were investigated in this study.	[41]

Table 3

Our works on bibliometric analysis

No	Title	Topic Discussion	Ref.
1.	A bibliometric analysis of materials research in Indonesian journal using VOSViewer	This paper discussed research trends in the field of materials.	[42]
2.	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	The use of mercury in gold mining was discussed in this study.	[43]
3.	Bibliometric analysis of educational research in 2017 to 2021 using VOSViewer: Google Scholar indexed research.	The bibliometric evaluation of Google Scholar-indexed papers in the context of education was discussed in this work.	[44]
4.	Bibliometric analysis of special needs education keyword using VOSviewer indexed by Google Scholar	This paper included a bibliometric analysis of Google Scholar-indexed papers related to special education.	[45]
5.	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis.	This study investigated the causes and patterns of research on sustainable development goals.	[46]
7.	Computational bibliometric analysis of research on science and Islam with VOSViewer: Scopus database in 2012 to 2022.	This study examined the evolution of research in the disciplines of science and Islam using information from Scopus-indexed article data.	[47]
8.	Resin matrix composition on the performance of brake pads made from durian seeds: From computational bibliometric literature analysis to experiment.	The impact of resin matrix composition on brake pad performance was discussed using bibliometric analysis in this study.	[48]
9.	Bibliometric Analysis of Briquette Research Trends During the Covid-19 Pandemic.	This paper investigated briquette research trends during the Covid-19 outbreak.	[49]
10	Computational Bibliometric Analysis on Publication of Techno-Economic Education.	This study employed bibliometric analysis to examine the evolution of publications in the field of techno-economic education.	[50]
11	How bibliographic dataset portrays decreasing number of scientific publications from Indonesia	Using bibliographic datasets, this study investigated how to describe the decline in the number of scientific publications in Indonesia.	[51]
12	Research trends from the Scopus database using keyword water hyacinth and ecosystem: A bibliometric literature review	This study appeared at research trends in the Scopus database related to water hyacinths and ecosystems.	[52]
13	Bibliometric analysis of high school keyword using VOSviewer indexed by google scholar	Bibliometric analysis was used in this study to examine research related to senior high school.	[53]
14	How to calculate bibliometric using VOSviewer with Publish or Perish (using Scopus data): Science education keywords	This research investigated how to analyse bibliometrics with VOSviewer and the Publish or Perish application.	[54]
15	Bibliometric analysis for understanding "science education" for "student with special needs" using VOSViewer	This study investigated bibliometric analysis in the context of science education and students with special needs.	[55]
16	Bibliometric analysis of research development in sports science with VOSViewer.	This study investigated the evolution of sports science research.	[56]
17	Bibliometric analysis of engineering research using VOSviewer indexed by Google Scholar	This study examined the evolution of research on technical topics using VOSviewer and data from Google Scholar-indexed articles.	[57]

No	Title	Topic Discussion	Ref.
18	Bibliometric computational mapping analysis of publications on mechanical engineering education using VOSViewer	This study investigated the advancement of research in the field of engineering education.	[58]
19	Introducing ASEAN Journal of Science and Engineering: A Bibliometric Analysis Study	This study examined and validated the impact and success of the ASEAN Journal of Science and Engineering in internationalization.	[59]
20	Introducing ASEAN Journal of Science and Engineering Education: A Bibliometric Analysis Study for Understanding Internationalization	This study examined and validated the impact and internationalization of the ASEAN Journal of Science and Engineering Education.	[60]
21	Exploring Iron Oxide's Role in Hydrogen Production: Bibliographic and Bibliometric Analysis	This study used VOSviewer to conduct bibliometric research on the Scopus database to assess scientific trends in metal oxide oxidation-reduction processes for energy storage systems. This research was reinforced with a review of the literature on the most recent theoretical discoveries in iron-based catalysis for hydrogen production and energy storage systems.	[61]
22	How Technology Can Change Educational Research? Definition, Factors for Improving Quality of Education and Computational Bibliometric Analysis	This study explained how strategies for creating and improving educational quality are developed, including communication, technology input (such as IT, ICT, AI, AR, and so on), curriculum and education level, and the relationship between social studies, humanities, science, and industry, as well as management and facilities.	[62]
23	Is Universitas Pendidikan Indonesia Ready for Internationalization? A Bibliometric Analysis in The Science and Technology-Related Publications	This study analyzed the publication data of Universitas Pendidikan Indonesia (UPI) and find out whether UPI is ready for internationalization	[63]
24	Social Impact and Internationalization of "Indonesian Journal of Science and Technology" the Best Journal in Indonesia: A Bibliometric Analysis	Using VOSViewer and RStudio, this study performed bibliometric scopus data analysis from publications in the Indonesian Journal of Science and Technology (IJoST) from 2016 to 2023 as the best journal in Indonesia (Q1 in scimagojr with the highest rank position).	[64]

2. Methodology

An illustration of the methodological design stages related to bibliometric analysis in particle and CFD research is shown in Figure 1. Detailed information for the experiment is in the following sections.
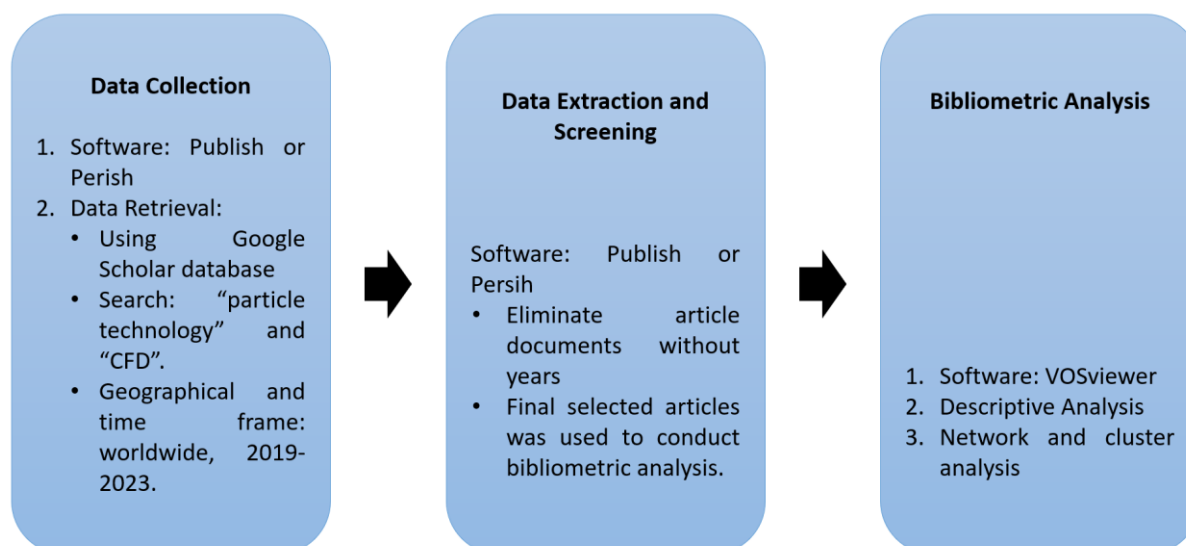
Fig. 1. The methodological framework of the study

2.1 Databases Searched

To investigate research on particle technology and CFD, we used Publish or Perish software to search and collect research in the form of scientific articles published on Google Scholar. Google Scholar is a database suite that covers a wide range of academic disciplines, including science, social sciences, arts, and humanities. Google Scholar is currently used in bibliometric analyses because it is one of the largest free scientific bibliographic databases. Google Scholar also relies on a large number of confidential databases, the contents of which are not available on the public internet. Consequently, Google Scholar is comparable to two other large databases that are expensive sources of scholarly bibliographies: ISI/Thomson's Web of Knowledge and Elsevier's Scopus. To gather data, the keywords "particle technology" and "CFD" were used to search for related articles in 2019-2023. The search for documents is then narrowed down by document types, such as journals, conference proceedings, and books, but patents are not included. Data harvesting yielded 985 research articles on particle technology and CFD. The articles are then imported into Microsoft Excel and saved in comma-separated value format (*.csv).

2.2 Data Extraction and Screening

After successfully collecting scientific articles in the first stage, data was extracted based on the name of the number of citations, article title, year of publication, type of outlet (journal, conference proceedings, or book section), journal title, publisher, and abstract. At this point, we decided to use various documents from the database, such as articles, books, articles relating to proceedings, book chapters, and other types of documents. The data is then screened based on the article title and the year it was published. Articles with irrelevant titles and an insufficient year of publication are discarded. The cleaned data is then entered into a Microsoft Excel file for further analysis with bibliometric software (e.g., VOSviewer).

2.3. Visualization Data

Based on data exported from the Google Scholar database, VOSviewer software is used to establish a special relationship with networks and maps. VOSviewer is the official software program

created by Van Eck and Waltman and developed for creating, visualizing, and exploring bibliographical maps. One of the main advantages of this software is its focus on the graphical representation of maps. It is particularly suitable when visualizing large maps, easy to interpret, and most commonly used for creating maps based on network data.

2.4 Analysis Data

At this point, the data that has been visualized and processed using Ms. Excel is analysed to obtain the results of research developments per year, the authors with the most research, the country, and the relationship between the authors and other authors, as well as countries with other countries. At this point, the clusters derived from the visualization results are also examined.

3. Results and Discussion
3.1 Publication Trend

The findings are based on the number of articles published in the Google Scholar database from 2019 to 2023. 985 articles are available relating to particle technology and CFD. Figure 2 depicts a significant decline in the growth of research over the last five years. The greatest increase in publication growth occurred in 2019, with 476 publications (38.2%). Meanwhile, 2023 seemed to be the lowest publication growth, with 42 publications (4.2%). The number of publications on particle technology and CFD falls to 320 (32.5%), 178 (18.07%), and 69 (7.0%) for publication years of 2020, 2021, and 2022, respectively.
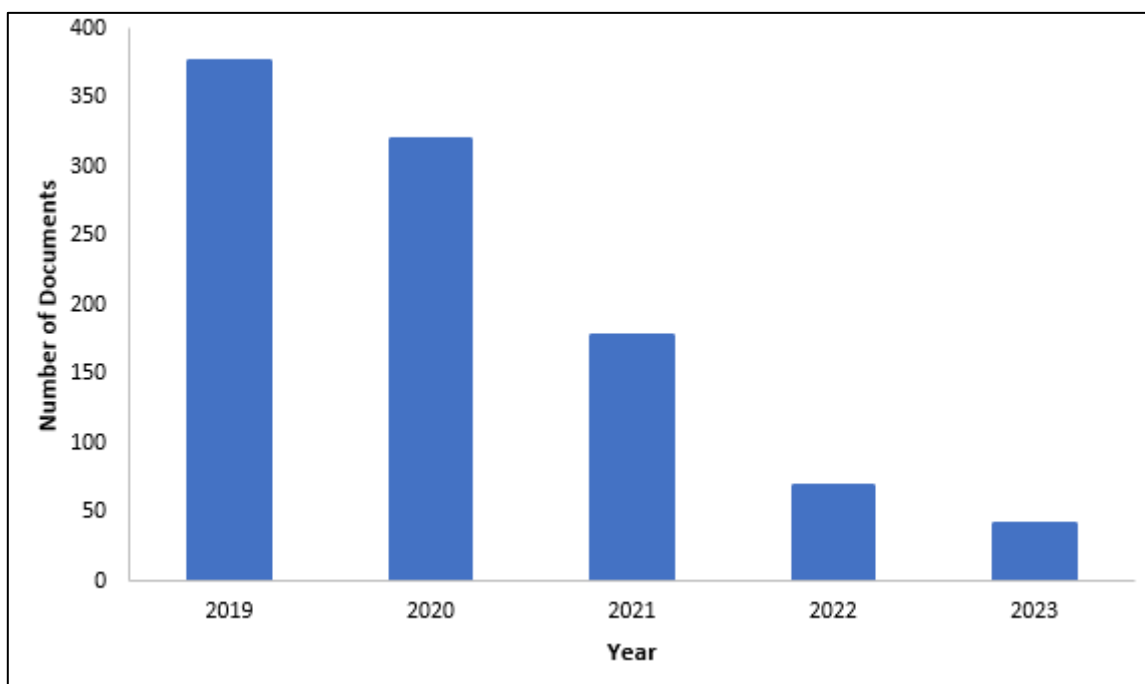
Fig. 2. The number of documents published for keywords "particle technology" and "CFD"

3.2 Top Article Document by the Most Citation, Publisher, and Country

Article documents with more than 110 citations consist of 23 documents. The top 10 documents with the most citations are presented in detail in Table 4. The most frequently referenced article is "New development of atomic layer deposition: processes, methods, and applications" written by

Oviroh *et al.,* [65] in 2019 with 324 citations. The 10th article with the most citation categories is the article entitled "Effects of spraying pressure and installation angle of nozzles on atomization characteristics of external spraying system at a fully-mechanized mining face" by Yang *et al.,* [66] in 2019 with 161 citations.

Table 4
Top 10 of Citation on Particle Technology and CFD Publication

No	Cites	Author	Title	Year	Journal Source	Publisher Source
1	324	Oviroh *et al.,* [65]	New development of atomic layer deposition: processes, methods and applications	2019	Science and technology of advanced materials	Taylor and Francis Online
2	243	Liu *et al.,* [67]	Research on tunnel ventilation systems: dust diffusion and pollution behaviour by air curtains based on CFD technology and field measurement	2019	Building and Environment	Elsevier
3	213	Rezaeiha *et al.,* [68]	On the accuracy of turbulence models for CFD simulations of vertical axis wind turbines	2019	Energy	Elsevier
4	179	Wang [69]	Continuum theory for dense gas-solid flow: A state-of-the-art review	2019	Chemical Engineering Science	Elsevier
5	178	Cai *et al.,* [70]	Effect of air flowrate on pollutant dispersion pattern of coal dust particles at fully mechanized mining face based on numerical simulation	2019	Fuel	Elsevier
6	172	Xiu *et al.,* [71]	Numerical simulation study on dust pollution characteristics and optimal dust control air flow rates during coal mine production	2020	Journal of Cleaner Production	Elsevier
7	171	Shao *et al.,* [72]	Risk assessment of airborne transmission of COVID-19 by asymptomatic individuals under different practical settings	2021	Journal of Aerosol Science	Elsevier
8	165	Kuang *et al.,* [73]	CFD-DEM modelling and simulation of pneumatic conveying: A review	2020	Powder Technology	Elsevier
9	165	Xu *et al.,* [74]	Multi-factor numerical simulation study on spray dust suppression device in coal mining process	2019	Energy	Elsevier
10	161	Yang *et al.,* [66]	Effects of spraying pressure and installation angle of nozzles on atomization characteristics of external spraying system at a fully-mechanized mining face	2019	Powder Technology	Elsevier

The number of citations is important because a large number of citations relates to the impact of the article on society. Indeed, it relates to the quality of the journal or publisher in selecting the best article. But, for some cases, it is important to note that while a high citation rate may indicate research impact, it is not the only measure of research quality. Other factors, such as the importance of the research question, the methodology used, and the contribution to the field, also play an important role in determining the impact of the paper. It has been mentioned previously that article documents with citations exceeding 110 citations consist of 23 articles that were identified from various publishers. The publisher with the highest number of citations is shown in Figure 3.
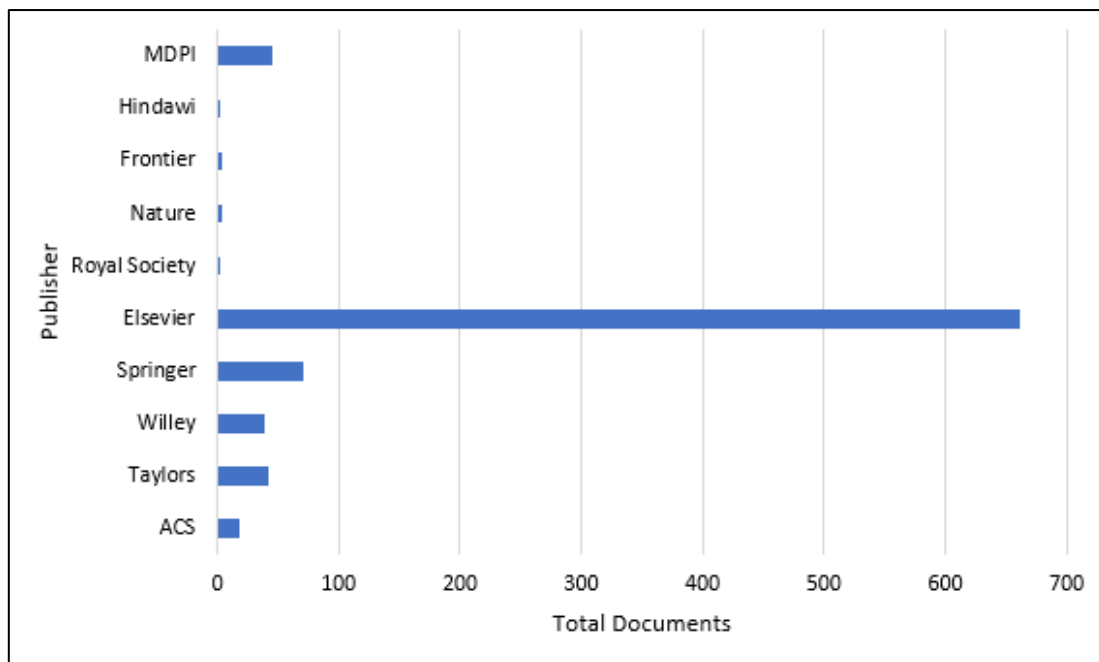
Fig. 3. Top 10 publisher sources with the highest number of citations

Furthermore, the number of citations received by research from a country can have several impacts both within the country itself and in the global research community. A higher number of citations generally indicates that research from that country is widely recognized and referenced by other researchers around the world. This can enhance a country's reputation in certain fields and contribute to its impact on the global research landscape. Data showing the participation of countries with the highest number of citations in related publications are presented in Table 5. Table 5 contains the total number of citations, publishers, and rankings of country publications selected from the top 9 most cited article document categories. The country with the most citations is China. After being generalized, based on the most citations from each country, the countries with the most citations contributed to the increase in citations for journal publishers. The order of publishers that were most frequently satisfactorily based on this case was Elsevier > Taylors and Francis > Degruyter.com > Hindawi > Nature. Countries with interesting research citations are often attractive partners for international collaboration. Researchers from other countries may seek collaborations to leverage the expertise and knowledge generated in high-citation research. Countries with strong research cultures and a history of producing high-impact work can attract talented researchers and find funding more easily. Researchers are often attracted to institutions and countries where their work is more likely to gain recognition and impact.

Table 5
Most citations by country selected from the top 10 most cited article

Rank	Country	Total of Citation	Publisher
1	China	907	Elsevier
2	South Africa	324	Taylor and Francis
3	USA	298	Elsevier
4	Australia	165	Elsevier
5	Swedia	161	Degruyter.com
6	Iran	146	Elsevier
7	Spain	133	Elsevier
8	Thailand	122	Hindawi
9	Sweden	113	Nature

3.3 Co-Authorship Analysis of Author

The visualization of the authors regarding the most active in CFD and particle technology research is shown in Figure 4. A total of 2402 authors participated in related research. There are different colors representing different clusters. Cluster 1 represented by a red circle, consists of 25 authors, while cluster 2 consists of 12 authors, represented by the green circle. Cluster 3 indicated by a blue circle, consists of 12 authors. Cluster 4 represented by the yellow circle, consists of 8 authors. Finally, clusters 5, 6, and 7 represented light blue, orange, and brown that consisted of 4, 4, and 2 items, respectively. The size of the circle represents the number of article documents. In other words, the greater the number of papers, the larger the circle. As shown in the map, Zhang (green circle), Wang (orange circle), and Yu (purple circle) are considered as the most prolific author in related research.

Fig. 4. Co-authorship analysis of authors

3.4 Visualization of Research Topic Area using VOSViewer

VOSviewer can display bibliometric maps in three different ways: network visualization, overlay visualization, and density visualization [43]. Detailed information regarding this matter is explained in our previous studies [75, 76]. Each cluster is represented by a colorful circle. The size of the circle is proportional to how many times the keywords appear in the title and abstract. As a result, the size of the letters and circles is dictated by the frequency with which they appear. The more frequently the keyword appears, the larger the font size and circle.

3.4.1 Network visualization

Network visualization shows the network between visualized terms. Relationships in the network visualization are depicted as networks or lines from one term to another. Figure 5 shows the clusters for each research topic area. From the identification results, it is known that there are four main clusters in the network, with a total link strength of 449 and 57 items, with the main nodes "size" in Cluster 1, "technology" in Cluster 2, and "bed" in Cluster 3, "modeling" in Cluster 4. In addition, the main nodes in this network were identified based on the links they had to other keywords and the

frequency with which they appeared across 111 articles. Each cluster is marked with a different color. Cluster 2 contains 14 terms, including air, CFD analysis, CFD method, CFD technology, development, experimental validation, fine particle, flow field, numerical analysis, numerical study, particle image velocimetry, particle motion, research, and technology reflected by the size of the largest circle the most often. The keywords that occurred the fewest were biomass, blast furnace, CFD DEM model, CFD study, fluid flow, heat transfer, modeling, numerical investigation, the present study, review, and validation. This demonstrates that certain terms are rarely mentioned. As a result, these keywords can be researched and evaluated further in future studies.
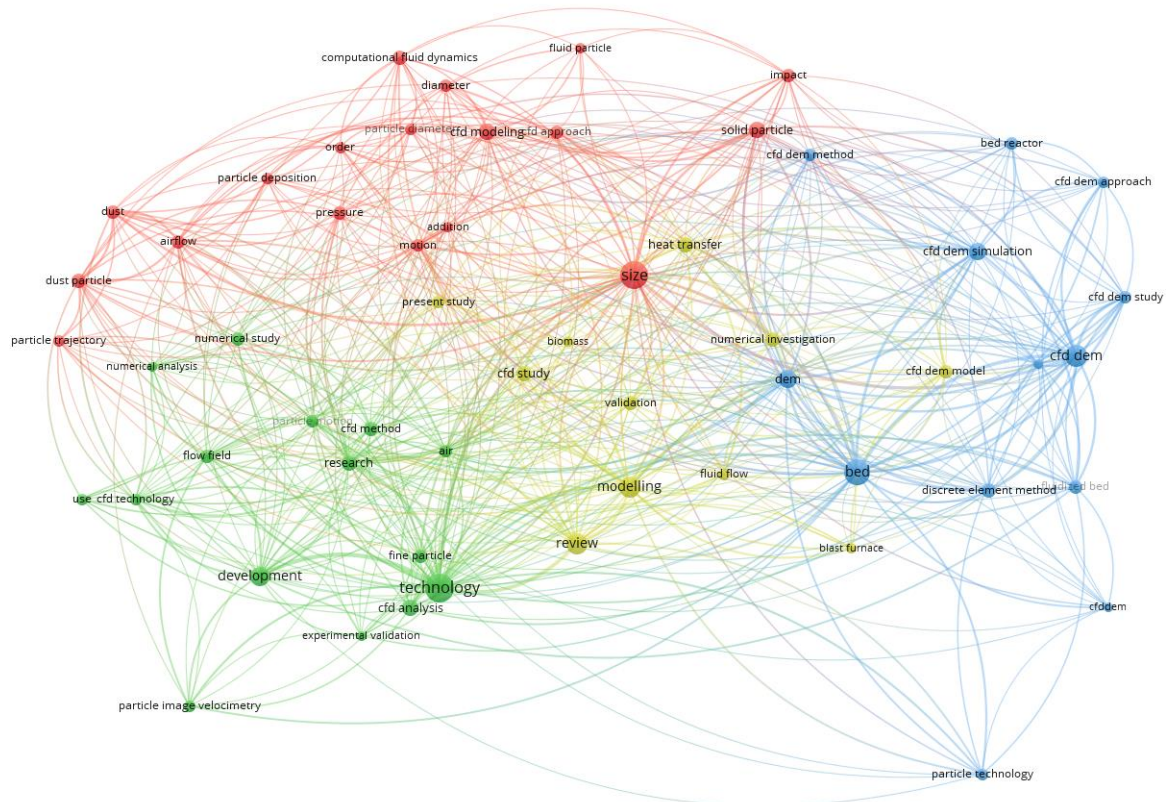

Fig. 5. Network visualization

3.4.2 Overlay visualization

Figure 6 illustrates a cluster analysis that uses keyword terms to find the most common and rare study subjects in research worldwide. An overlay network visualization is used to depict trending themes. Topics or keywords that contribute to the research are given in the overlay visualization network based on the year of publication. In 2020, the terms "CFD," "particle image velocimetry," "airflow," and "dem simulation" with yellow nodes were not studied intensively (see Figure 6).
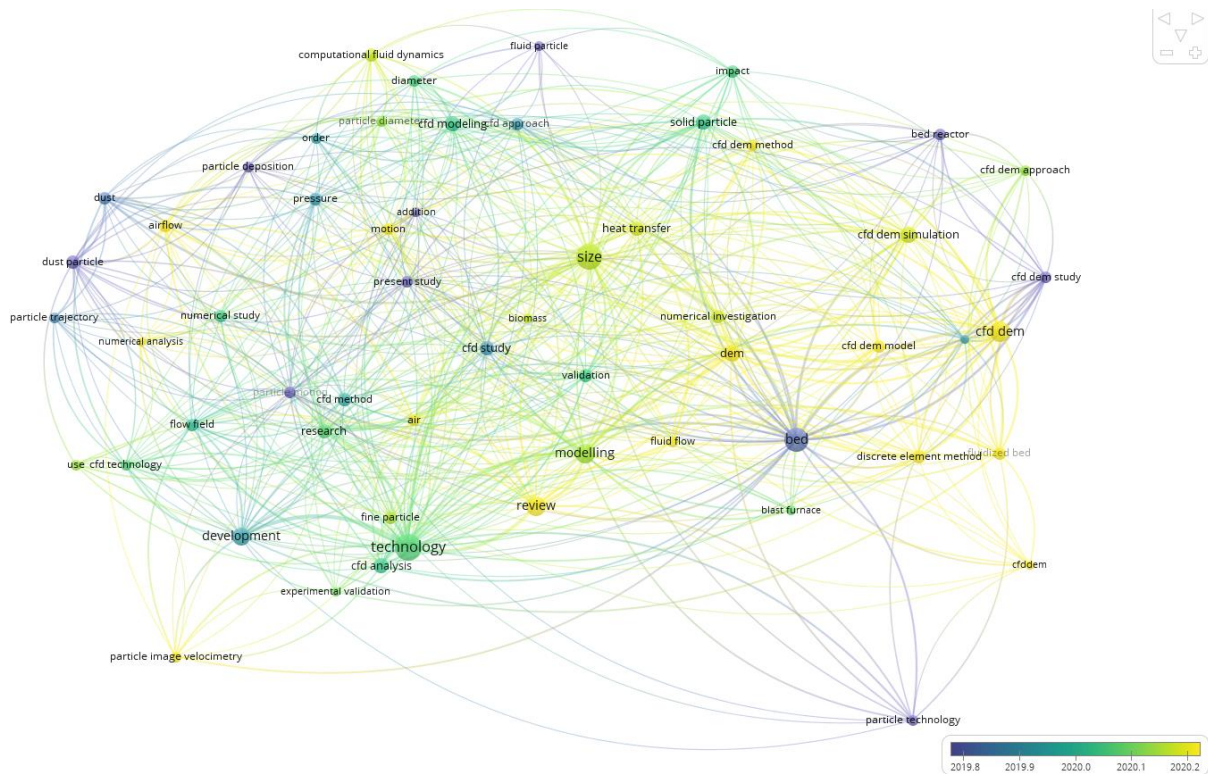
Fig. 6. Overlay visualization

3.4.3 Density visualization

Cluster density is the number of elements that have the same label as display items. Each dot has a different hue depending on the density of the object. This means that the color of a point on the graph is determined by the number of items associated with other objects. This section is very useful for understanding the basic layout of a bibliometric map by identifying which aspects are relevant to the study. Throughout this worksheet, the terms that are frequently used in publications can be identified. A map depiction of the co-word research growth density with the keyword's particle technology and CFD is shown in Figure 7. Figure 7 illustrates that the technology keywords have a fairly high density and are surrounded by many additional keywords that are close, such as the keywords "CFD," " fine particle," and "experimental validation." Some dense keywords give rise to some research contact with the subject, indicating that the subject is still not fully investigated. Various thoughts arising from the expansion of transdisciplinary science can lead to new research gaps [43, 77]. This provides potential for future research in particle technology in CFD.

Fig. 7. Density visualization

4. Conclusion

Based on the findings obtained, the development of particle technology and CFD research, especially in Google Scholar-indexed journals, is important. This is confirmed by the excellent number of publications in 2019, reaching a total of 376 publications (38.7%). The results of the top citation analysis show that 23 publications have excellent citations, passing above 110 citations, where the publisher Elsevier and researchers from China dominate the article. Author visualization analysis shows that the author named Zhang is the most prolific author in this topic area. The results of the network visualization analysis showed that the most frequent keyword is "technology" and the rare keyword is "blast furnace." The most recent related research in 2023 focused on the terms "CFD," "particle image velocimetry," "airflow," and "DEM simulation." Furthermore, the results of the density analysis show that some keywords that have been studied in depth are "technology," "CFD analysis," "fine particles," and "experimental validation." Finally, this research is expected to assist researchers in determining the topics to be studied and can also be a reference for research related to particle technology and CFD.

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