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Concept of Computational Fluid Dynamics Design and Analysis Tool for Food Industry: A Bibliometric

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ABSTRACT

Technology that is currently in demand is CFD. By simulating fluid flow around a product on a computer, the computational fluid dynamics (CFD) technique allows designers of new products to be tested. This research aims to analyze the bibliometrics of CFD publications as a design tool in the food industry to determine concepts, trends, and contributions of previous research. Computational Fluid Dynamics (CFD) is a technology used to test product designs through computer simulations of fluid flow around the product. The use of technology in various industries, such as the food industry, is essential to create better products or services. This research uses a bibliometric analysis method supported by theoretical analysis. This research consists of 5 steps, namely (i) determining the research theme for formulating keywords, (ii) collecting publication documents, (iii) data processing, (iv) bibliometric analysis, and (v) preparing a report. The keywords used in this research are "Computational Fluid Dynamics Design (CFD) in Food Industry." The results of the publication search found a total of 211 documents from 1992 to 2023. The average number of publications was 6.59. The trend of CFD publications in the food industry was first carried out in 1992. The development of this publication has been fluctuating, and there has been an increase in publications in the last five years (2019 - 2023). Research publications regarding CFD in the food industry are grouped into 20 subject areas. Contributions to this research consisted of 159 authors, 160 affiliates, and 51 countries. Completing this research will likely provide information regarding publication sources and contributions made by several scientists from various affiliates and countries worldwide.

1. Introduction

The food and beverage industry is one of the industries proliferating worldwide [1], including in Indonesia. Various food and drinks with an attractive appearance continue to be produced to increase aesthetic value and consumer appeal. The food and beverage production process includes selecting raw materials, food and beverage processing, food and beverage quality testing, packaging, and the food and beverage distribution process. Every process that takes place must be controlled

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so that the final product produced is safe and suitable for consumption by consumers. That is the reason why many reports on food and beverage [2-10].

The development of the food and beverage industry must be balanced with developments in the technology used in the industry. The use of technology in various industries has become very important to create better products or services [11]. Technology in the food sector is no less critical; innovation in this field is closely related to the food and drink ingredients we consume daily [12]. Food technology provides practical solutions to meet increasing human needs. Due to busy schedules, some people need more time to cook food and drinks. Therefore, technology is essential in providing food that is high in nutrition, fast, and safe for consumption [13]. Besides that, using technology can also increase the effectiveness of food production in the industrial world.

One technology that can be used to support the development of the food industry is Computational Fluid Dynamics (CFD) technology. CFD is a technology that is currently popular. Computational Fluid Dynamics (CFD) is a technology used to test product designs through computer simulations of fluid flow around the product [14, 15]. CFD is used in the automotive, aircraft, building, and other industries to test product designs before production [16]. Using CFD, designers can improve product designs to make products more efficient and safer. The use of CFDs has excellent benefits for the industry. Companies can create more efficient, cheaper, easier-to-produce, safer, and more environmentally friendly products through CFD technology. Along with increasingly rapid technological developments,

Several previous studies discuss CFD [17], including the application of CFD in modeling and designing ventilation systems in the agricultural industry [18], a literature review of the application of CFD in the food industry [19], a review of CFD as a design tool and effective and efficient analysis for the food industry [20], perspective analysis of the state of CFD aerospace technology [21], and the application of CFD for drying process simulations [22]. In general, many previous studies on CFD used the literature review method, so the research objective discusses CFD concept analysis. Based on previous research, several studies link CFD with the food industry [19, 20], but both are still limited to literature reviews. Thus, there has been no research linking CFD with the food industry using bibliometric analysis to determine trends in CFD research in the food industry combined with theoretical analysis to support and strengthen the research.

Therefore, this research aims to analyze the bibliometrics of CFD publications as a design tool in the food industry to determine concepts, trends, and contributions of previous research. This research was conducted to provide consideration for similar research in determining research themes, especially those related to the use of CFD in the food industry. Apart from that, this research provides information regarding publication sources and contributions made by several scientists from various affiliates and countries worldwide. Detailed information for the previous studies on bibliometric analysis is shown in Table 1.

Table 1
Previous studies on bibliometric analysis

No	Title	Topic discussion	Ref.
1	Dental suction aerosol: Bibliometric analysis.	In this study, the evolution of dental aerosol suction was explained by distribution of bibliometrics maps and research trends using VOSviewer.	[23]
2	A bibliometric analysis of Covid-19 researches using VOSViewer.	Using bibliometric analysis, this study examines the growth of writing throughout the COVID-19 era.	[24]
3	The latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: Literature review and bibliometric analysis	This study reviewed the literature on pure biodiesel's advantages and disadvantages for engine performance.	[25]

4	A bibliometric analysis of management bioenergy research using VOSviewer application	The subject of bioenergy management was studied for research trends and advancements in this study.	[26]
5	Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis	This study investigated the usage of benzotriazole ionic salt liquid as a solvent for empty palm oil fruit bunches using bibliometric analysis and VOSviewer.	[27]
6	Biomass-based supercapacitors electrodes for electrical energy storage systems activated using chemical activation method: A literature review and bibliometric analysis.	It was debated whether biomass-based carbon may be used as the electrode of a supercapacitor to provide extremely efficient current transmission in energy storage devices.	[28]
7	Bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSViewer	In this study, mapping analysis and VOSviewer software were combined to conduct a bibliometric analysis of nFs for medical science.	[29]
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.	This study's goal was to discuss scientometric studies of SA and its derivatives' organizational development and future possibilities.	[30]
9	Correlation between process engineering and special needs from bibliometric analysis perspectives.	This study included discussion of the integration of mapping analysis using the VOSviewer application.	[31]
10	Bibliometric analysis for understanding the correlation between chemistry and special needs education using VOSviewer indexed by Google.	The use of VOSviewer in conjunction with mapping analysis was covered in this work.	[32]
11	Computing bibliometric analysis with mapping visualization using VOSviewer on “pharmacy” and “special needs” research data in 2017-2021.	The next five years (2017–2021) were examined in this study with regard to mapping visualization in research on pharmaceutical subjects and special requirements.	[33]
12	Nutritional research mapping for endurance sports: A bibliometric analysis.	This study looked into research mapping in the area of nutrition for endurance athletes.	[34]
13	Bibliometric and visualized analysis of scientific publications on geotechnics fields.	This study used bibliometric distribution maps from the VOSviewer tool to assess the development of research in geotechnical engineering.	[35]
14	A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation.	This study looked at the descriptions of research advancements in engineering and science education.	[36]
15	What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using VOSviewer indexed by Google Scholar?	In this study, "Special Needs of Chemical Engineering" are analyzed using the VOSviewer tool.	[37]
16	Counselling guidance in science education: Definition, literature review, and bibliometric analysis.	This study uses a literature review and bibliometric analysis to examine the issue of guidance and counseling in science education.	[38]
17	Phytochemical profile and biological activities of ethylacetate extract of peanut (Arachis hypogaea L.) stems: In-vitro and in-silico studies with bibliometric analysis.	This study examined the chemical composition and pharmacological activity of A.hypogaea stems in vitro and in silico.	[39]
18	A bibliometric analysis of materials research in Indonesian journal using VOSViewer	This article reviewed current materials research trends.	[40]
19	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	In this study, mercury use in gold mining was covered.	[41]
20	Bibliometric analysis of educational research in 2017 to 2021 using VOSViewer: Google Scholar indexed research.	This work explored the bibliometric analysis of Google Scholar-indexed works in the context of education.	[42]

21	Bibliometric analysis of special needs education keyword using VOSviewer indexed by Google Scholar	A bibliometric analysis of special education-related articles that were indexed by Google Scholar was included in this paper.	[43]
22	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis.	This study examined the origins and trends in the literature on sustainable development objectives.	[44]
23	Computational bibliometric analysis of research on science and Islam with VOSViewer: Scopus database in 2012 to 2022.	This study examined the origins and trends in the literature on sustainable development objectives.	[45]
24	Resin matrix composition on the performance of brake pads made from durian seeds: From computational bibliometric literature analysis to experiment.	The results of this study's bibliometric analysis were used to discuss the effect of resin matrix composition on brake pad performance.	[46]
25	Bibliometric Analysis of Briquette Research Trends During the Covid-19 Pandemic.	The trends in briquette research during the Covid-19 outbreak were examined in this publication.	[47]
26	Computational Bibliometric Analysis on Publication of Techno-Economic Education.	This study used bibliometric analysis to look at how publications in the area of techno-economic education have changed over time.	[48]
27	How bibliographic dataset portrays decreasing number of scientific publications from Indonesia	This study looked into the best way to explain the drop in scientific publications in Indonesia using bibliographic datasets.	[49]
28	Research trends from the Scopus database using keyword water hyacinth and ecosystem: A bibliometric literature review	This paper was found in research trends on water hyacinths and ecosystems in the Scopus database.	[50]
29	Bibliometric analysis of high school keyword using VOSviewer indexed by google scholar	This study employed bibliometric analysis to look at studies on senior high school.	[51]
30	How to calculate bibliometric using VOSviewer with Publish or Perish (using Scopus data): Science education keywords	This study looked into the use of Publish or Perish and VOSviewer for bibliometric analysis.	[52]
31	Bibliometric analysis for understanding “science education” for “student with special needs” using VOSViewer	The bibliometric analysis of science education and children with special needs was examined in this study.	[53]
32	Bibliometric analysis of research development in sports science with VOSViewer.	This study looked into how sports science research has changed throughout time.	[54]
33	Bibliometric analysis of engineering research using VOSviewer indexed by Google Scholar	This study used data from papers that were indexed by Google Scholar along with VOSviewer to assess the development of research on technical subjects.	[55]
34	Bibliometric computational mapping analysis of publications on mechanical engineering education using VOSViewer	The development of research in the area of engineering education was the subject of this study.	[56]
35	Introducing ASEAN Journal of Science and Engineering: A Bibliometric Analysis Study	The impact and accomplishments of the ASEAN Journal of Science and Engineering on internationalization were evaluated and validated in this study.	[57]
36	Introducing ASEAN Journal of Science and Engineering Education: A Bibliometric Analysis Study for Understanding Internationalization	The influence and internationalization of the ASEAN Journal of Science and Engineering Education were investigated and validated in this study.	[58]
37	Exploring Iron Oxide's Role in Hydrogen Production: Bibliographic and Bibliometric Analysis	The Scopus database was used in this study's bibliometric analysis of scientific trends in metal oxide oxidation-reduction processes for energy storage systems. A survey of the literature on the most current theoretical advancements in iron-based catalysis for hydrogen production and energy storage systems was used to support this research.	[59]
37	How Technology Can Change Educational Research?	According to this study, strategies for developing and enhancing educational quality are developed in relation to communication, technology input (such	[60]

	Definition, Factors for Improving Quality of Education and Computational Bibliometric Analysis	as IT, ICT, AI, AR, and so forth), curriculum, educational level, and the connections between social studies, humanities, science, and industry, as well as management and facilities.	
38	Is Universitas Pendidikan Indonesia Ready for Internationalization? A Bibliometric Analysis in The Science and Technology-Related Publications	The purpose of this study was to determine whether Universitas Pendidikan Indonesia (UPI) was prepared for internationalization by analyzing its publication statistics.	[61]
39	Social Impact and Internationalization of "Indonesian Journal of Science and Technology" the Best Journal in Indonesia: A Bibliometric Analysis	This study did bibliometric scopus data analysis from publications in the Indonesian Journal of Science and Technology (IJoST), the best journal in Indonesia (Q1 in scimagojr with the highest rank position), from 2016 to 2023 using VOSViewer and RStudio.	[62]
40	Mapping of nanotechnology research in animal science: Scientometric analysis	This essay examines animal science and the latest developments in that field.	[63]
41	How Language and Technology Can Improve Student Learning Quality in Engineering? Definition, Factors for Enhancing Students Comprehension, and Computational Bibliometric Analysis	This study examines how to improve students' engineering learning comprehension as well as language research trends for engineering learning using Bibliometric Computation analysis.	[64]
42	How to Improve Student Comprehension in Learning Chemistry by Making Strategy in Language Education? Definition, Factors for Enhancing Students Comprehension, and Computational Bibliometric Analysis	This study examines trends in language research for chemistry learning and bibliometric computational analysis for improving students' understanding of chemistry instruction.	[65]
43	Enhancing student understanding on the concept of carbon biochar production in islamic boarding school through collaborative practicum with experimental demonstration for supporting sustainable development goals (SDGs)	This study improves students' comprehension of the idea of producing biochar carbon in Islamic boarding schools.	[66]

2. Methodology

The method used in this research is bibliometric analysis supported by theoretical analysis regarding Computational Fluid Dynamics Design (CFD) in the Food Industry. *Bibliometric analysis* is a method that uses statistical mathematics to analyze and visualize bibliometric data quantitatively. The research publication data analyzed comes from the Scopus database. Data collection was carried out on September 21, 2023. This research consisted of 5 steps, which were carried out based on the results of the adaptation of bibliometric analysis research and literature review carried out by Al Husaeni & Nandiyanto [67]. The research procedure steps are:

(i) The first step, we determined the research theme, the research theme was used as a reference for formulating search keywords.
(ii) The second step, we collected publication data from the Scopus page (https://www.scopus.com/).
(iii) In the third step, we processed bibliometric data from articles that had been obtained using Microsoft Excel and RStudio applications.
(iv) In the fourth step, we carried out a bibliometric mapping analysis with co-occurrence types based on keywords, countries and authors using the VOSviewer application.
(v) In the fifth step, we analyzed the results of data processing and bibliometric mapping. The final result of this step is a research report.

The keywords used in this research are "Computational Fluid Dynamics Design (CFD) in Food Industry". The search syntax on the Scopus page that we use is ((“Computational Fluid Dynamics Design”) OR (“CFD”) AND (“Food Industry”)). Keyword searches are carried out with the prerequisite of finding the article's keywords, title, and abstract. The articles used in this research have been published indexed by Scopus. In this study, we did not determine the research year range, so we analyzed the initial year of publication regarding CFD in the food industry in Scopus until 2023. The publication search results found a total of 211 documents from 1992 to 2023.

3. Theoretical Framework

3.1 Computational Fluid Dynamics Design (CFD)

Computational Fluid Dynamics (CFD) is a method of calculating, predicting, and approximating fluid flow numerically with the help of computers [68, 69]. CFD approaches the numerical method and uses fluid equations [70, 71]. CFD is a calculation method that controls dimensions, area, and volume by utilizing computer computing assistance to calculate each dividing element. CFDs have received widespread attention from the international community since the advent of digital computers. CFD has become an integral part of the engineering design and analysis environment in many companies due to its ability to predict the performance of a new design or process before it is produced or implemented (see Table 2).

There has been much research on CFD or the application of CFD, namely CFD for Comparative Investigation of Resistance Prediction for Surface Combatant Ship Model [72], Prediction of Erosion Rate in Two Elbows for Coal-Air Flow [73], Hydrodynamic Analysis Inside a Circulating Fluidized Bed Boiler Based on Time Change [74], Combustion of Pulverized Coconut Shell in Lab-Scaled Incinerator Rig [75], Semi Twisted Curve Blade Vortex Turbine Performance at Runner Rotation Speed Variation [76], CFD Analysis of Different Sizes of Savonius Rotor Wind Turbine [77], and the use of CFD on the performance of tesla turbines driven by internal combustion engine exhaust gases [78].

Table 2
Subject area of CFD application

Industrial applications	• Aerospace • Architecture • Automotive • Biomedical • Chemical and Process • Combustion • Electronics and computers • Glass manufacturing • HVAC (heat, ventilation and cooling) • Petroleum • Power • Marine	• Mechanical • Metallurgical • Nuclear • Train design • Turbomachinery • Water
Environmental applications	• Atmospheric pollution • Climate calculations • Fire in buildings Oceanic flows Pollution of natural waters Safety	
Physiological applications	• Cardiovascular flows (heart, major vessels) Flow in lungs and breathing passages	

3.2 Benefits of using CFDs

CFD has grown from a mathematical curiosity to an essential tool in almost every branch of fluid dynamics. Most CFD results will improve performance, reliability, more confident scale-up, product consistency, and factory productivity [79]. CFD is sometimes used to analyze new systems before deciding which and how much validation testing needs to be performed. The advantages of CFDs can be categorized as [19].

(i) Provides a detailed understanding of flow distribution, weight loss, mass and heat transfer, particulate separation, etc.
(ii) CFD makes it possible to evaluate geometry changes with much less time and cost than laboratory testing.
(iii) CFDs can quickly answer many 'what if' questions.
(iv) CFD can reduce the problem of scaling up because the models are based on fundamental physics and are not dependent on scale.
(v) CFD is beneficial in simulating conditions where it is impossible to make detailed measurements, such as high temperatures or hazardous environments inside the oven.
(vi) CFD tools can highlight the root cause, not just the impact when evaluating factory issues. This is because CFD is a proactive analysis and design tool.

3.3 CFD Analysis Process

When conducting CFD analysis, the analyst will state the problem and use scientific knowledge to express it mathematically. Then, CFD software will implement this knowledge and express the problem scientifically. Finally, the computer will perform the calculations determined by the CFD software, and the analyst will examine and interpret the results. In principle, three different significant tasks must be performed to perform a CFD simulation.

3.3.1 Pre-processing

Pre-processing is all tasks before the numerical solution process in CFD analysis. Pre-processing involves thinking about the problem, connecting, and creating a computational model. Problem thinking is the first stage in using CFD. At the problem-thinking stage, an analyst should consider the problem flow and try to understand it as much as possible. The second stage is meshing. At this stage, the analyst must create a problem domain that needs to be analyzed. Then, the problem domain is further divided into cells, also known as volumes and elements. Figure 1 shows an example of the meshing structure of a commercial air blast cooler with a ham inside [19, 80].

Once the meshing is complete, the boundaries of the problem domain can be found, and the necessary boundary conditions, determined at an early stage, must be applied. These conditions and several fluid parameters and physical properties determine the actual flow problem to be solved. Advanced CFD software packages have programs to perform the following operations: defining a grid of points, as well as volumes or elements, defining geometric boundaries, applying boundary conditions, defining initial conditions, setting fluid properties, and setting numerical values of control parameters.

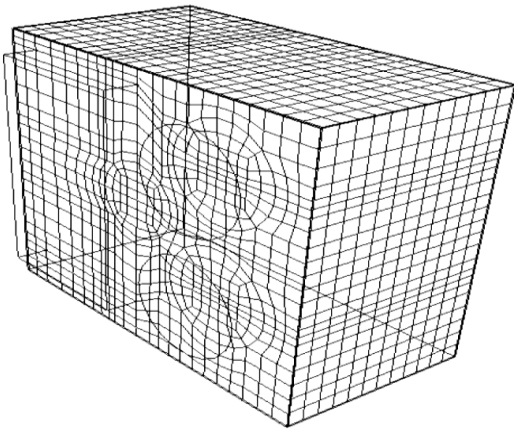

Fig. 1. Air blast cooling mesh structure [80]

3.3.2 Processing

Processing involves using computers to solve mathematical equations for fluid flow. Once the meshing is complete, the model input values must be determined, and then the software can solve the equation of state for each cell until acceptable convergence is achieved. This step is at the core of CFD analysis and can take time.

3.3.3 Post-processing

The post-processing program is used to evaluate the data produced by CFD analysis. When the model has been completed, the results can be analyzed numerically and graphically. Figure 2 gives an example of the velocity vector in the chiller shown in Figure 1, and Figure 3 shows the corresponding temperature distribution during cooling [80]. When some results have been obtained, they must be analyzed first to check whether the solution is satisfactory and then to determine the actual flow data required from the simulation.

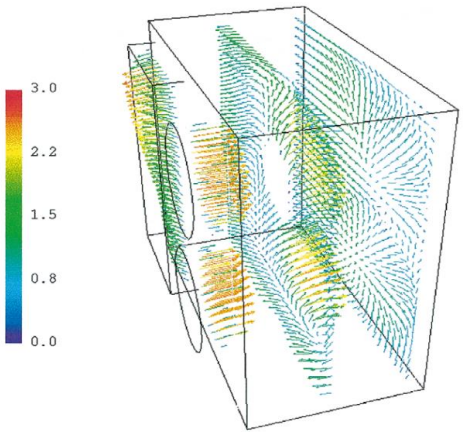

Fig. 2. Example of flow field in a chiller predicted by CFD code [80]

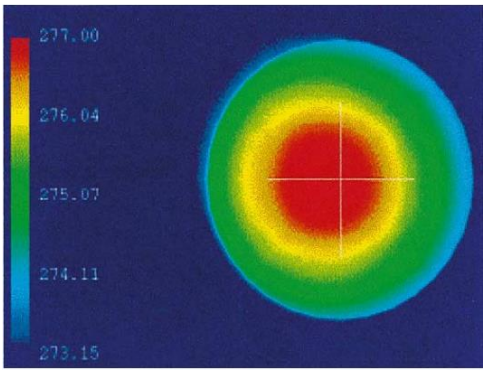

Fig. 3. Example of ham temperature distribution during cooling [80]

3.4 Application of CFD in the Food Industry

CFD is a technology used in many branches of the food industry. CFD is used at every production stage, from preparing and processing raw materials to packaging finished products [81]. CFD is increasingly used to improve, optimize, and design processes in food technology [81]. The food processing sector can benefit from using CFD as a research tool to improve design processes and understanding of the fundamental physical properties of fluid dynamics in many areas, including drying, sterilization, mixing, cooling, and other application areas.

3D modeling makes it possible to reduce the time and costs associated with building prototypes of food processing machines and devices. This type of software in the hands of qualified operators will enable machine manufacturers to meet the requirements of food processors, including reducing losses during production, increasing process efficiency, or reducing energy consumption. It is assumed that CFD will become an indispensable element in the food industry's design of equipment and technological lines. While there are some drawbacks, such as the need to have large reserves of computing power, technological developments will make these problems less significant over time.

The application of CFD in the food business can help to understand complex physical processes better. In addition, there is additional literature on specific CFD application areas, including cleanroom design [82], static mixers [83], and pipe flow. In the next section, we explain the literature analysis or analysis of previous research regarding the application of CFD to the food business in more detail as a result of the bibliometric analysis of research data.

4. Results and Discussion

4.1 Trend in Number of Publications and Citations per Year Articles

Figure 4 shows the publication history of the number of articles regarding Computational Fluid Dynamics Design (CFD) in the Food Industry. Based on the results of research data searches, it is known that the trend of research publications regarding CFD in the food industry was first carried out in 1992. In the 32 years of publication data, an annual research report was obtained, which shows that the development of publications regarding CFD in the Food industry has fluctuated and has experienced an increase in publications in the last 5 years (2019 - 2023). The number of publications increased significantly from 1998, with 1 publication to 12 in 2002. However, in 2003, the number of publications decreased significantly, with only 1 publication. The years with the highest publication productivity occurred in 2020 and 2022, namely 15 publications. Meanwhile, the years with the lowest publication productivity occurred in 1994, 1995, and 2005, with no publications regarding

CFDs in the Food industry. The average number of publications regarding CFDs in the Food industry is 6.59.

The description of the number of publications each year is based on the number of documents found; no published documents were found in 1994, 1995, and 2005. In 1992, 1993, 1997, 1998, and 2003 1 published document was found. In 1996, 1 published document was found. In 1999 and 2008 3 published documents were found, and in 2000, 2010, and 2014 4 published documents were found. In 2004, 5 published documents were found. 6 publication documents were found in 2001, 2012, and 2016. Meanwhile, in 2006 7 publication documents were found. In 2007, 2011, and 2015 8 published documents were found, in 2009 11 published documents were found, in 2002, 2018, and 2023 12 published documents were found, in 2019 13 published documents were found, in 2013 and 2017.

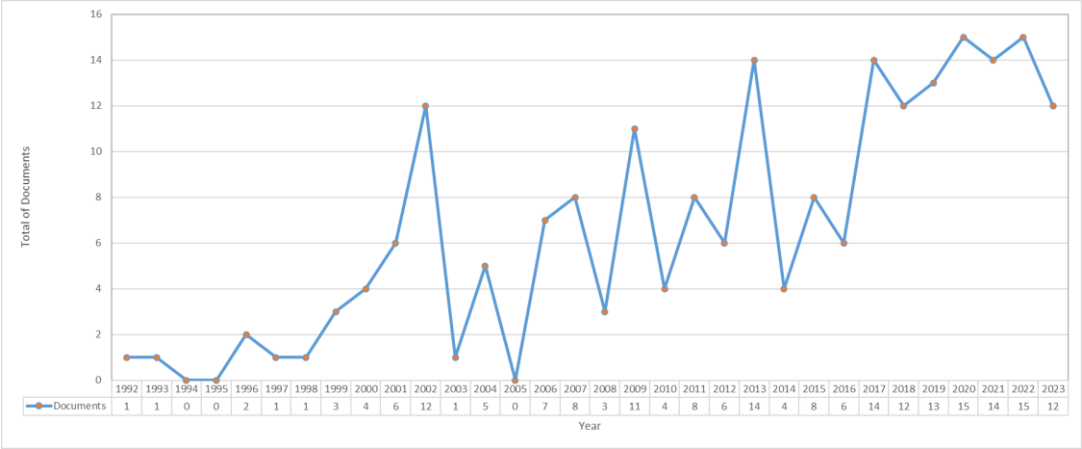

Fig. 4. Number of publications per year

The total annual publications on CFD research in the food industry, as shown in Figure 4, come from the distribution of various types of documents, including articles (128 documents), conference papers (38 documents), book chapters (18 documents), reviews (15 documents), editorials (5 documents), book (3 documents), conference review (3 documents), and short survey (1 document). The distribution of document types analyzed in this research is shown in Figure 5. The document types most often found in research publications regarding CFD in the food industry are articles at 60.7% and conference papers at 18.0%. The document with the lowest total is the short survey at 0.5%.

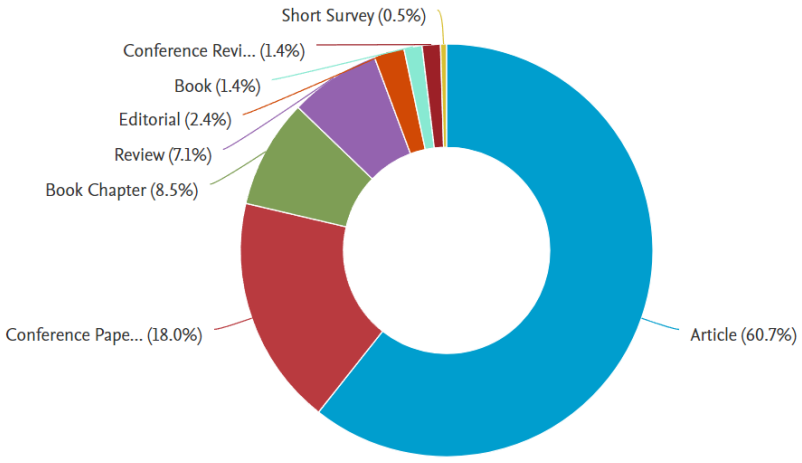

Fig. 5. Distribution of document types

Table 3 shows details of publication trends and the number of citations for articles regarding CFDs in the food industry published in Scopus-indexed journals. Table 3 shows the average total document citations per year. Citations in academic writing provide recognition to the author, support research arguments, and help build a strong foundation in writing a scientific work [84]. Citation is the most commonly used approach to determine influence, publication quality, and relationships between authors, research groups, research topics, or countries [85]. The development of citation ranking lists highlights published works that have the potential to influence future patterns of clinical practice and research.

Based on the data in Table 3, it is known that the number of citations to published articles regarding CFDs in the food industry is still relatively low. Articles that have been cited only occur in articles published in 2023. The article "Extrusion-based 3D food printing: printability assessment and improvement techniques" by Kadival *et al.,* [81] has the highest number of citations, namely 6 total citations. Kadival *et al.,* [81] discuss considerations of 3D printing technology in the food industry. Kadival *et al.,* [81] conducted a printability evaluation, including assessing extrudabilities, dimensional accuracy, and stability of 3D printed objects using computational fluid dynamics (CFD) modelling and qualitative or quantitative methods. Another article with the highest number of citations is the article "Review of CFD-DEM Modelling of Wet Fluidized Bed Granulation and Coating Processes" written by Song *et al.,* [86]. Song *et al.,* [86] introduced the basic theory of CFD-DEM from the governing equations, force calculations, and coupling schemes, then presented the application of CFD-DEM in the simulation of wet fluidized bed granulation and coating. The article written by Kadival *et al.,* [81] was cited 6 times, while the article written by Song *et al.,* [86] was cited 3 times.

Table 3
Most cited articles

No	Author	Title	Year	T.C	TC per year
1	Kadival *et al.,* [81]	Extrusion-based 3D food printing: printability assessment and improvement techniques	2023	6	6.00
2	Song *et al.,* [86]	Review of CFD-DEM Modeling of Wet Fluidized Bed Granulation and Coating Processes	2023	3	3.00
3	Szpicer *et al.,* [87]	Application of computational fluid dynamics simulations in food industry	2023	2	2.00
4	Tariq *et al.,* [88]	Effective waste heat recovery from engine exhaust using fin prolonged heat exchanger with graphene oxide nanoparticles	2023	2	2.00
5	Petrosino *et al.,* [89]	Modeling of specific migration from food contact materials	2023	0	0.00

Note. TC=Total Citations

4.2 Trends in Subjects and Research Topics

Figure 6 shows the distribution of previous research subject areas regarding CFD in the food industry based on data from Scopus. Research publications regarding CFD in the food industry are grouped into 20 different subject areas, namely engineering (101 documents), agricultural and biological sciences (80 documents), chemical engineering (65 documents), chemistry (34 documents), computer science (25 documents), physics and astronomy (23 documents), biochemistry genetics and molecular biology (22 documents), environmental science (14 documents), energy (12 documents), materials science (10 documents), mathematics (9 documents), pharmacology toxicology and pharmaceutics (5 documents), medicine (4 documents), business management and accounting (3 documents), economics econometrics and finance (3 documents),

decision sciences (2 documents), immunology and microbiology (2 documents), social sciences (2 documents), and nursing (1 document). The subject area with the highest number of research publications regarding CFD in the food industry is engineering, with 101 documents. The subject area with the least number of research documents regarding CFD in the food industry is nursing, with a total of 1 document. Figure 7 shows a visualization of research on CFD in the food industry from 2019 to 2023. Figure 8 shows a publication overlay visualization of research on CFD in the food industry. The visualization overlay shows the distribution of research years to see updates on using terms in related research.

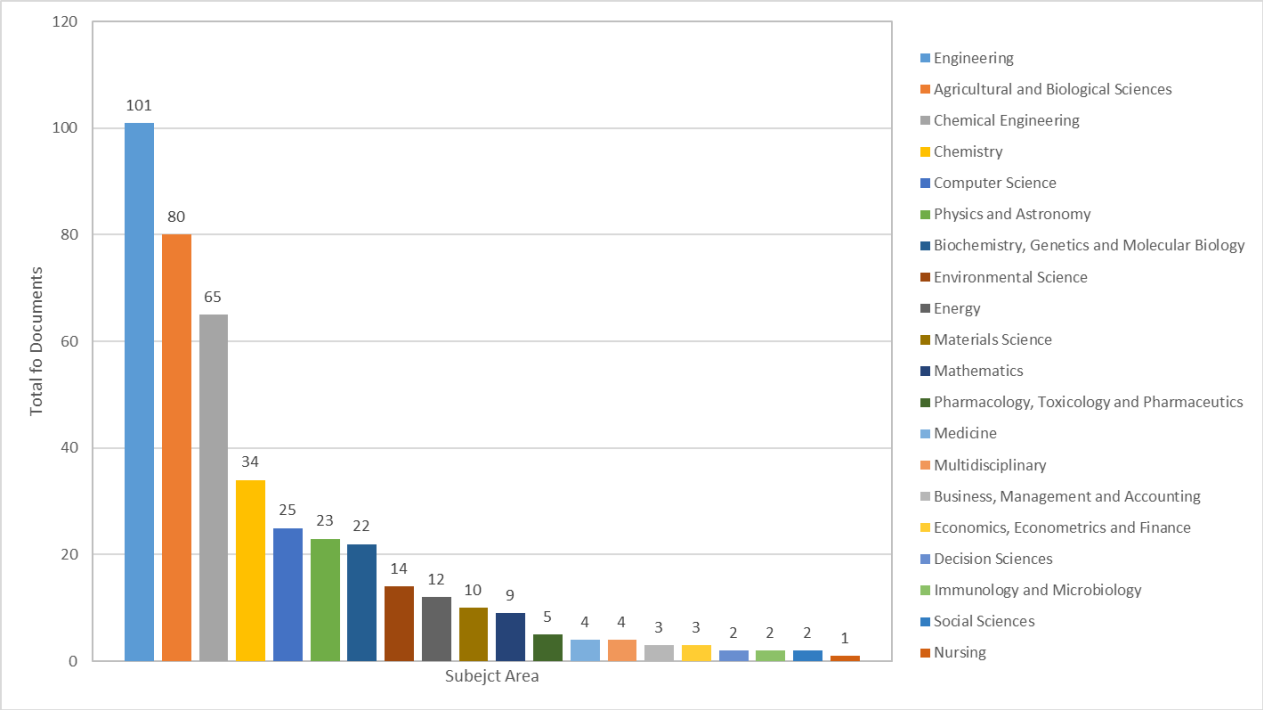

Fig. 6. Distribution of research area subjects

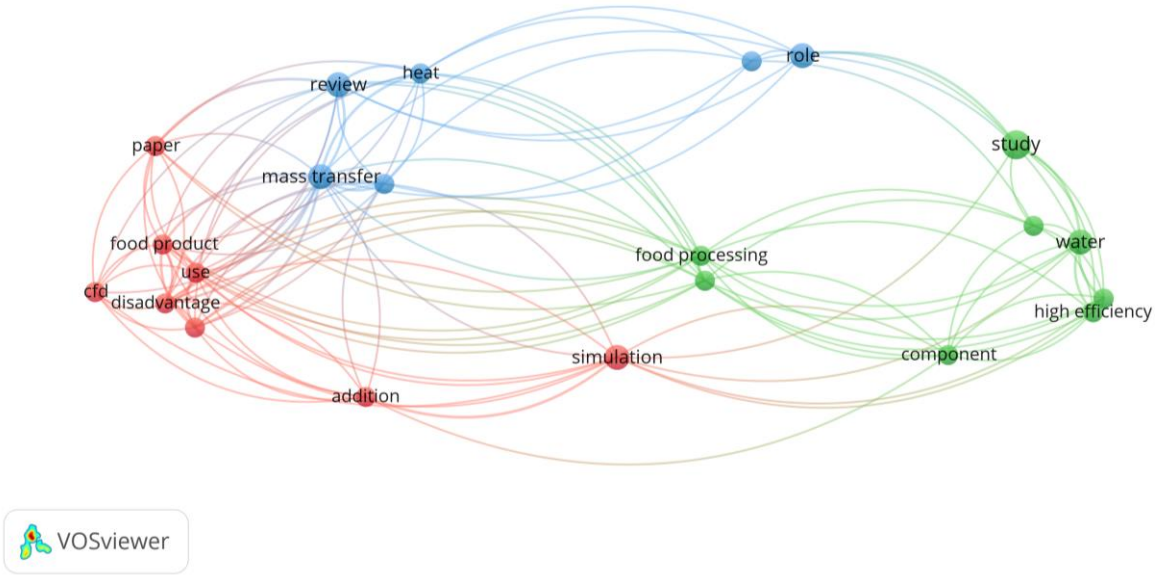

Fig. 7. Network visualization of research on CFD in the food industry

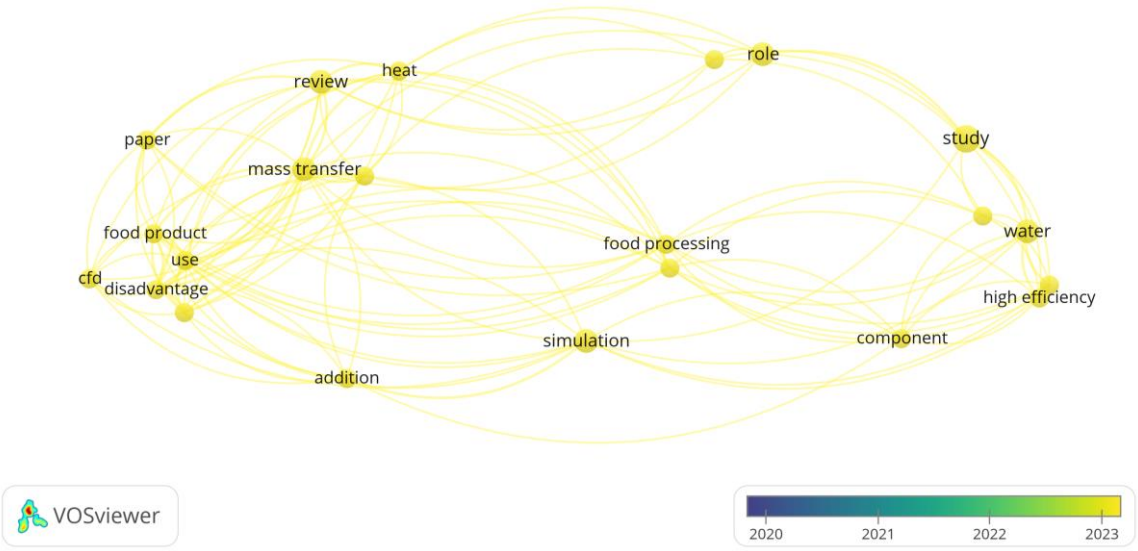

Fig. 8. Overlay visualization of research on CFD in the food industry

4.3 Analysis of Research Author Contributions

In research publications regarding CFD in the food industry, 159 scientists or researchers have contributed. Figure 9 shows the 15 authors who have contributed the most articles to CFD research publications in the food industry. Sun is the author who has the highest number of published CFD articles in the food industry, namely 12 articles. Then, Norton has 5 articles. Roucco, Mirade, Knoerzer, and De Bonis are the authors with the third most articles with 4 publications. De Jong and Daudin have written 3 articles on CFD in the food industry. Meanwhile, Chen, Casari, Buratto, Bouanini, Asteriadou, Anandharamakrishnan, and Aldi have each written 2 published articles regarding CFDs in the food industry.

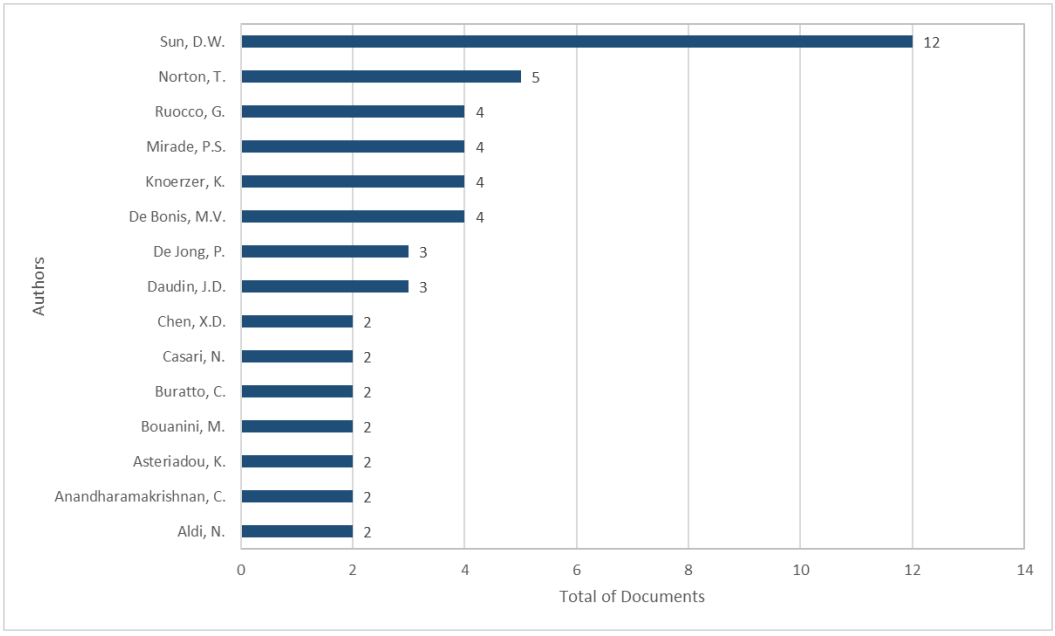

Fig. 9. Authors with the highest contributions

4.4 Analysis of Affiliate and Country Research Contributions

This research analyzes affiliates and countries contributing to CFD research publications in the food industry. As many as 160 affiliates have contributed to CFD research publications in the food industry. Figure 10 shows the distribution of author affiliations in the top 16 with the highest number of publications. University College Dublin is the affiliate with the highest number of CFD publications in the food industry, namely 11 documents, followed by the National University of Ireland with 8 documents. Unilever is the affiliate with the third highest total contribution, namely 4 documents. Ministry of Education of the People's Republic of China Universiti Kebangsaan Malaysia, NIZO food research, Università degli Studi della Basilicata, Nanjing Agricultural University, Commonwealth Scientific and Industrial Research Organization, and Campden BRI have published 3 documents. Meanwhile, Central Food Technological Research, Institute India, Pennsylvania State University, Politechnika Koszalinska, Bialystok University of Technology, and Faculty of Engineering published 2 documents on CFD in the food industry.

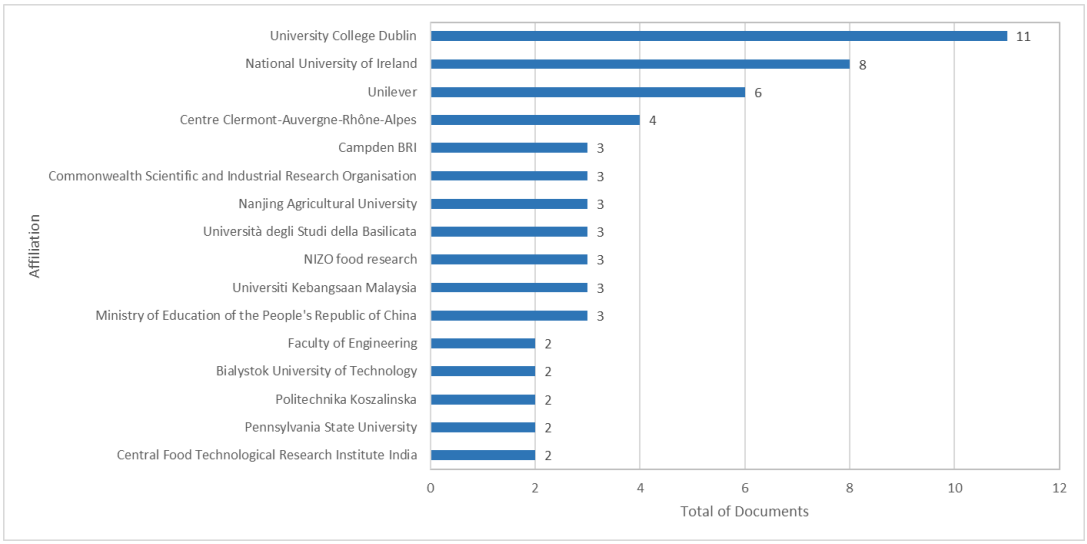

Fig. 10. Affiliate contributions

Figure 11 shows the country's contribution to writing articles with the theme of CFD in the food industry. Fifty-one countries have contributed to research on CFD in the food industry. However, Figure 11 shows the 17 countries with the highest article contributions > 4 documents. Countries that have contributed to CFD research in the food industry are the United Kingdom, India, China, United States, Irelan d, Italy, France, Iran, Germany, Malaysia, Poland, Australia, Netherlands, Brazil, South Korea, Spain, Turkey, Canada, Portugal, Sweden, Thailand, Algeria, Belgium, Japan, Bulgaria, Czech Republic, Egypt, Greece, Hungary, Indonesia, Iraq, New Zealand, Pakistan, Saudi Arabia, Serbia, Taiwan, Austria, Bangladesh, Belarus, Denmark, Ecuador, Finland, Hong Kong, Jordan, Morocco, Romania, Russian Federation, Singapore, South Africa, Tunisia,

The United Kingdom is the country with the highest number of research publication contributions regarding CFD in the food industry, with 26 documents found. India, with 20 documents, China, with 16 documents, and the United States, with 16 documents, are the countries in the top 5 with the most contributions. This distribution of countries shows that CFD research in the food industry does not only occur or focus on one region but has been carried out by researchers from the continents of Asia, Europe, America, Australia, and Africa.

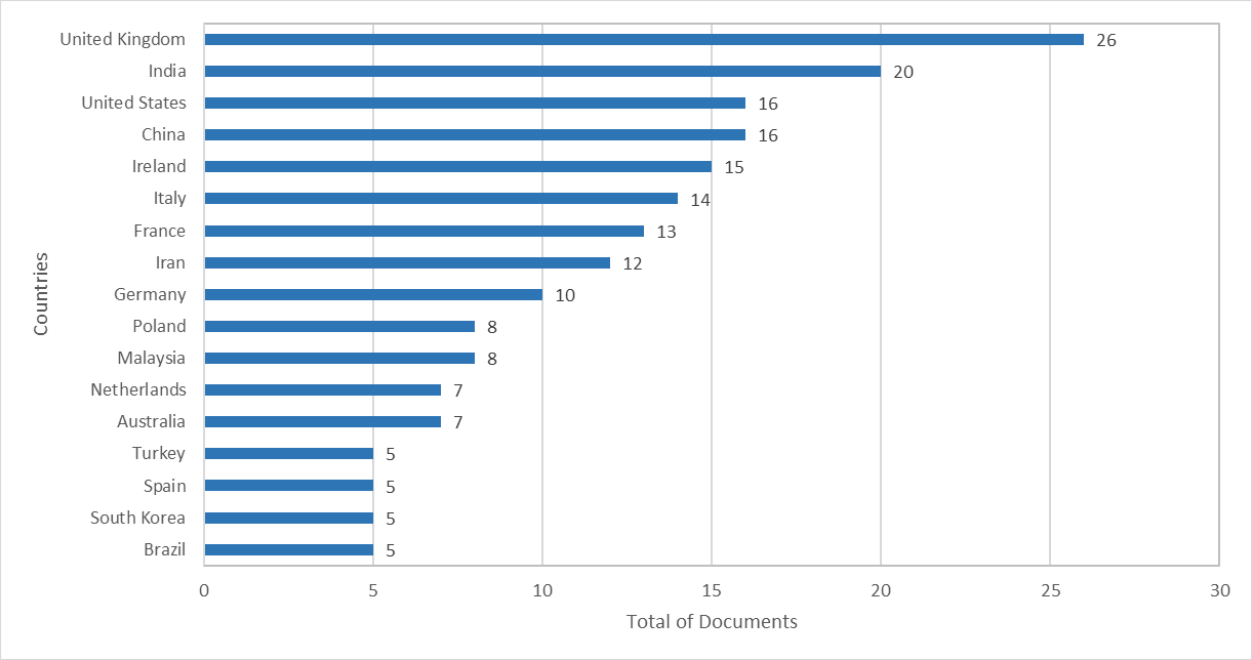

Fig. 11. Country contributions

Figure 12 presents Countries' Scientific Production by R Studio Analysis. Based on Countries' Scientific Production by R Studio Analysis, it is known that 9 countries have scientific production contributions, namely Australia, China, India, Pakistan, Poland, Italy, Turkey, Iran, and Saudi Arabia. In the distribution of country contributions, we also analyzed the countries with the most citations (see Figure 13). India occupies the first position with the highest number of citations, 6 times. Furthermore, there are China, Pakistan, and Poland, which have several citations 2. Meanwhile, Italy and Turkey do not have any or have never been cited.

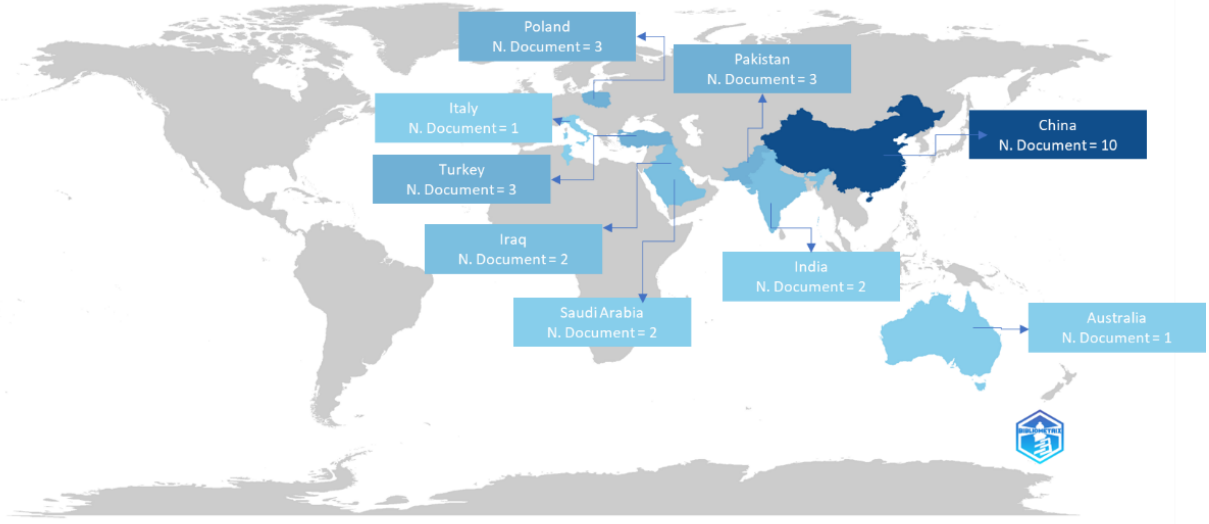

Fig. 12. Countries' scientific production by R studio analysis

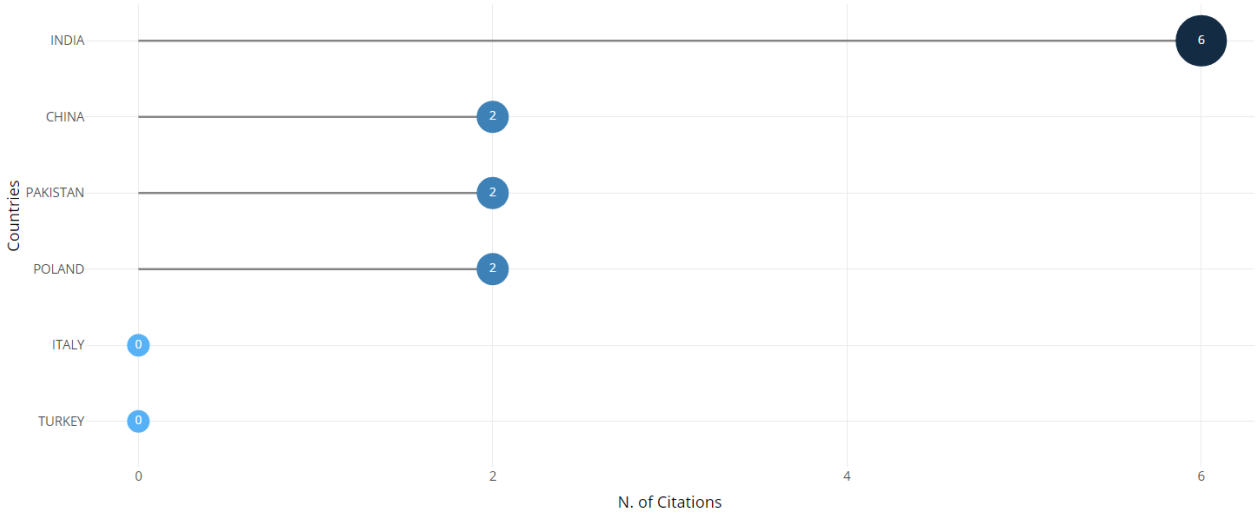

Fig. 13. Most cited countries

4.5 Analysis of Publication Sources

Several articles analyzed in this research were published by several international publication sources indexed by Scopus. Therefore, we conducted a publication source analysis. Future researchers can use data from the analysis of publication sources as a reference source for selecting places to publish their work. One hundred fifteen publication sources publish research documents regarding CFD in the food industry. Figure 14 shows the 12 research publication sources with the most documents. The 12 research publication sources that have the highest number of documents are Advanced Materials Research (3 documents), Applied Thermal Engineering (3 documents), Chemical Engineering Transactions (3 documents), Drying Technology (3 documents), Innovative Food Science and Emerging Technologies (3 documents),

Other publication sources are Chemical Engineering Journal, Chemical Engineering Science, Critical Reviews In Food Science And Nutrition, European Food Research And Technology, Food And Bioprocess Technology, Food Engineering Series, International Journal Of Thermal Sciences, International Review Of Mechanical Engineering, Italian Journal Of Food Science, Journal Of Engineering Science And Technology, Journal Of Physics Conference Series, Materials Today Proceedings, Plos One, Processes, Ultrasonics Sonochemistry, Acta Horticulturae, Aerosol Science And Technology, American Society Of Mechanical Engineers Pressure Vessels And Piping Division Publication PVP, Applied Energy, Applied Mechanics And Materials, Applied Sciences Switzerland, Biomedical Microdevices, Bioresource Technology, Biosystems Engineering, Biotechnology And Bioprocess Engineering, Bulgarian Chemical Communications, Canadian Journal Of Chemical Engineering, Chemical Engineering And Processing Process Intensification, Chemical Papers, Chemical Product And Process Modeling, Chemie Ingenieur Technik, Colloids And Surfaces A Physicochemical And Engineering Aspects, Communications In Agricultural And Applied Biological Sciences, Comprehensive Reviews In Food Science And Food Safety, Computational Studies, Computer Aided Chemical Engineering, Computer Applications In Engineering Education, Computers And Chemical Engineering, Energies, Energy, Energy And Buildings, Energy Procedia, Environmental Science And Pollution Research, Fme Transactions, Food And Chemical Toxicology, Food Bioscience, Food Research, Food Technology, Heat And Mass Transfer Waerme und Stoffuebertragung, Heat Transfer Research, IMA Journal Of Management Mathematics, Industrial And Engineering Chemistry Research, Industrial Robot, Industrie Alimentari, International Communications In Heat And Mass Transfer, International Journal For Numerical Methods In Fluids, International Journal Of Applied

Mechanics, International Journal Of Automotive And Mechanical Engineering, International Journal Of Engineering And Advanced Technology, International Journal Of Environmental Research And Public Health, International Journal Of Fluid Mechanics Research, International Journal Of Food Science, International Journal Of Heat And Fluid Flow, International Journal Of Production Economics, Iop Conference Series Materials Science And Engineering, Iranian Journal Of Chemistry And Chemical Engineering, Japan Journal Of Food Engineering,Journal Of Advanced Research In Dynamical And Control Systems, Journal Of Agricultural Science And Technology, Journal Of Energy Storage, Journal Of Engineering Mathematics, Journal Of Environmental Chemical Engineering, Journal Of Mathematical Fluid Mechanics, Journal Of Mechanical Engineering Research And Developments, Journal Of Membrane Science, Journal Of Nanomaterials, Journal Of Stored Products Research, Journal Of Supercritical Fluids, Journal Of The Brazilian Society Of Mechanical Sciences And Engineering, Journal Of The Indian Chemical Society, Journal Of Thermal Analysis And Calorimetry, Journal Of Visualization, Lait, Lecture Notes In Electrical Engineering, Lecture Notes In Mechanical Engineering, Measurement Science And Technology, Middle East Journal Of Scientific Research, Mm Science Journal, Nutrition And Food Science,Periodica Polytechnica Chemical Engineering, Pharmaceutical Manufacturing And Packing Sourcer, Pharmaceutical Technology Europe, Polish Journal Of Chemical Technology, Proceedings Of Meetings On Acoustics, Proceedings Of The American Control Conference, Proceedings Of The Institution Of Mechanical Engineers Part E Journal Of Process Mechanical Engineering, Recent Patents On Biotechnology, Renewable Energy, Sensors Switzerland, Shipin Kexue Food Science, Toxicological Sciences, Transactions Of The Canadian Society For Mechanical Engineering, and World Applied Sciences Journal.Proceedings Of The Institution Of Mechanical Engineers Part E Journal Of Process Mechanical Engineering, Recent Patents On Biotechnology, Renewable Energy, Sensors Switzerland, Shipin Kexue Food Science, Toxicological Sciences, Transactions Of The Canadian Society For Mechanical Engineering, and World Applied Sciences Journal.Proceedings Of The Institution Of Mechanical Engineers Part E Journal Of Process Mechanical Engineering, Recent Patents On Biotechnology, Renewable Energy, Sensors Switzerland, Shipin Kexue Food Science, Toxicological Sciences, Transactions Of The Canadian Society For Mechanical Engineering, and World Applied Sciences Journal.

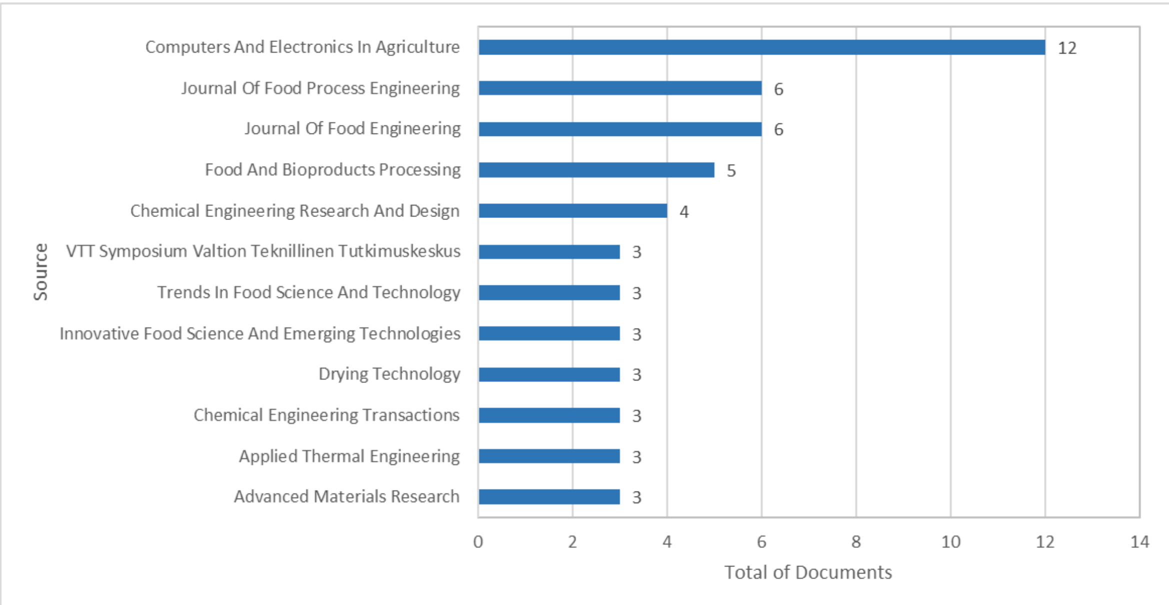

Fig. 14. Most contribution publication source

5. Conclusion

Computational Fluid Dynamics (CFD) is a technology used to test product designs through computer simulations of fluid flow around the product. The use of technology in various industries, such as the food industry, is essential to create better products or services. This research aims to analyze the bibliometrics of CFD publications as a design tool in the food industry to determine concepts, trends, and contributions of previous research. The results of the publication search found a total of 211 documents from 1992 to 2023. The average number of publications was 6.59. The development of this publication has fluctuated, and there has been an increase in publications in the last 5 years (2019 - 2023). The years with the highest publication productivity occurred in 2020 and 2022, namely 15 publications. Research publications regarding CFD in the food industry are grouped into 20 subject areas. The subject area with the highest number of research publications regarding CFD in the food industry is engineering, with 101 documents, while the lowest is nursing, with a total of 1 document. Contributions to this research consisted of 159 authors, 160 affiliates, and 51 countries. University College Dublin is the affiliate with the highest number of CFD publications in the food industry, namely 11 documents. CFD research in the food industry does not only occur or focus on one region. However, it has been carried out by researchers from the continents of Asia, Europe, America, Australia, and Africa.

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