

Bibliometric Computational Mapping Analysis of Publications on Ferrous Ferric Oxide (Fe_3O_4) Nanoparticles Using Vosviewer

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Anisa Noorlela¹ and Asep Bayu Dani Nandiyanto¹

¹Universitas Pendidikan Indonesia, Indonesia

Corresponding author:

Anisa Noorlela

Universitas Pendidikan Indonesia, Indonesia

Email: anisanoorlela@upi.edu

Abstract

This study aims to analyze computational bibliometric mapping using VOSviewer software on Fe_3O_4 nanoparticles. Article data collection was carried out by searching through the Google Scholar database with the keyword " Fe_3O_4 nanoparticles, nanoparticles, Fe_3O_4 " using Publish or Perish software. It was found that 998 articles indexed by Google Scholar with the categories of article titles, abstracts, and keywords in the period 2012 to 2022. The data obtained in the Publish or Perish software were then analyzed using Microsoft Excel. The results of bibliometric analysis mapping can be visualized using VOSviewer software. The results of the analysis of research developments related to ferrosferric oxide (Fe_3O_4) nanoparticles fluctuated from 2012 to 2019. The largest increase in publications was in 2017 and 2018 with the number of publications being 110 and 109. In the last 3 years there has been a drastic decline, namely in 2020 as many as 96 publications, 2021 as many as 73 publications, and 2022 as many as 27 publications. These data indicate that research on ferrosferric oxide (Fe_3O_4) nanoparticles is relatively unstable and interest in ferrosferric oxide (Fe_3O_4) nanoparticles has decreased. The use of VOSviewer is intended to analyze the relationship of the keyword " Fe_3O_4 nanoparticles, nanoparticles, Fe_3O_4 " which has been published with related fields. The results of this study are expected to be a reference for future research so that the topic of nanoparticles, especially Fe_3O_4 nanoparticles can continue to development.

Keywords: Bibliometric analysis, google scholar database, VOSviewer, Fe_3O_4 nanoparticles

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INTRODUCTION

Nanoparticles are defined as dispersed particulates or solid particles with particle sizes ranging from 10 - 100 nm. The very small particle size is used to design and arrange or manipulate materials so that materials with new properties and functions are produced. Nanoparticle materials have been of great interest to researchers because they exhibit very different physical and chemical properties from the bulk material, such as mechanical, electronic, magnetic, thermal, catalytic and optical stability. Nanoparticle chemistry is a relatively young branch of chemical research. In the industrial world, nanoparticles are used as construction materials, pigments, and stained glass [1]. Research states that nanoparticles for transition metals are widely used as heterogeneous catalysts which are very profitable for petrochemical companies. Until the late 20th century, nanoparticle chemistry did not develop into a rigorous academic field when the availability of electron microscopy and other modern characterization techniques could equip researchers to analyze nanometer-sized objects [2].

Ferrus ferric oxide (Fe_3O_4) or better known as magnetite compound has ferromagnetic properties and has an iron content of 72% of the mass of iron. In nanoparticle size, magnetite is superparamagnetic, has a high coercivity field value, and a low Curie temperature [3]. Fe_3O_4 is one of the iron oxides that shows the strongest magnetic properties compared to other iron oxides, so it is widely used in various fields, including as a heavy metal binder [4]. While Fe_3O_4 nanoparticles are one type of magnetic material that is quite promising because it has characteristics that are quite potential in the application of Giant Magnetoresistive (GMR) magnetic sensors. The characteristics of Fe_3O_4 nanoparticles include high saturation magnetization values, soft magnets, small coercive fields, and low anisotropy values, and have superparamagnetic properties [5]. With the times, Fe_3O_4 is very much needed as a basic material for making magnets which until now the need continues to increase along with the increasing need for electronic equipment for the community. Indonesia has a wealth of natural resources, one of which is iron sand mining. Iron sand contains mineral magnetite (Fe_3O_4) which has high magnetic susceptibility. Fe_3O_4 nanoparticles are expected to be able to become the base material for permanent magnets, because usually the raw material for nanoparticle size magnets will provide product quality with excellent magnetic properties [4].

Bibliometric analysis is a method used to see the development of research in various fields including the field of nanoparticles. Bibliometric analysis is defined as a statistical evaluation of published scientific articles, books, or chapters of a book, and is an effective method for measuring the impact of publications on the academic community [6]. Based on the Google Scholar database, many researches on bibliometric analysis have been carried out, including bibliometric analysis of magnetite nanoparticles [7], bibliometric analysis on Publication of Techno-Economic Education [8], bibliometric analysis of Nanocrystalline Cellulose Production Research [9], Vocational school [10], Nano Metal-Organic Frameworks Synthesis [11], Chemical Engineering [12,13,14], Management Bioenergy Research [15], Carbon Nanotubes Synthesis Research [16], Materials Research [17], Mechanical Engineering Education [18], Engineering Research [19], Engine performance [20], Scientific publications [21], Educational Research [22], Dataset Portrays Decreasing Number of Scientific Publication

[23], and bibliometric analysis in economics [24]. In addition, there are also several examples of previous research on Fe₃O₄ obtained from the google scholar database, including the synthesis, characterization, and magnetic adsorption properties of Fe₃O₄ graphene nanocomposite [25], Synthesis and Application of Magnetic Nanoparticles of Magnetite (Fe₃O₄) for Lead Removal (Pb²⁺) and Chromium (Cr⁶⁺) from water [26], and radical induced degradation of acetaminophen with Fe₃O₄ magnetic nanoparticles as heterogeneous activator of peroxymonosulfate [27].

The results of computational research on bibliometric analysis mapping can be visualized using VOSviewer software. The use of VOSviewer is intended to analyze the relationship of the keyword "Fe₃O₄ nanoparticles, nanoparticles, Fe₃O₄" which has been published in related fields. The results of this study are expected to be a reference for further research so that the topic of nanoparticles, especially regarding the synthesis, characterization, and application of ferrous ferric (Fe₃O₄) nanoparticles can continue to development.

METHODS

Article data collection was carried out by searching through the Google Scholar database with the keyword "Fe₃O₄ nanoparticles, nanoparticles, Fe₃O₄" using Publish or Perish software. Selected database of articles indexed by Google Scholar because it is open source, in contrast to Scopus which cannot be accessed freely. The data obtained in the Publish or Perish software were then analyzed using Microsoft Excel. The results of bibliometric analysis mapping can be visualized using VOSviewer software. Research by Al Husaeni et al. provides detailed information on how to install and use the Publish or Perish software and the VOSviewer software step by step [25]. Research by Azizah et al. also provides detailed information on the procedures for searching the article database on Google Scholar [26].

Computational research on bibliometric analysis mapping on ferrous ferric oxide (Fe₃O₄) nanoparticles required several steps, including:

- (i) Install Publish or Perish software and VOSviewer software,
- (ii) Collection of article data through the Google Scholar database with the keyword "Fe₃O₄ nanoparticles, nanoparticles, Fe₃O₄" using Publish or Perish software,
- (iii) The article data obtained in the Publish or Perish software is then analyzed using the Microsoft Excel application,
- (iv) The results of computational research on bibliometric analysis mapping can be visualized using VOSviewer software, and
- (v) Analysis of the results of data and images displayed on the VOSviewer software.

Article data searched on Publish or Perish software is useful for selecting article publications using the keywords "Fe₃O₄ nanoparticles, nanoparticles, Fe₃O₄" based on the title category and publication abstract. Selected articles indexed by Google Scholar in the period 2012 to 2022. The data obtained were collected in September 2022. Articles that meet the criteria for computational research on bibliometric analysis mapping are exported into file type (.ris) for the research system, and exported into file type (*.csv) for comma-separated formats. The results of the article data that have been obtained by the Microsoft excel application are then mapped using the VOSviewer software. The use

Table 1. Fe₃O₄ Nanoparticles Publication Data

No.	Authors	Title	Year	Cites
1	Y Yao et al.	Synthesis, characterization, and adsorption properties of magnetic Fe ₃ O ₄ graphene nanocomposite	2012	571
2	M Ghaedi et al.	Modeling of competitive ultrasonic assisted removal of the dyes–Methylene blue and Safranin-O using Fe ₃ O ₄ nanoparticles	2015	571
3	S Rajput et al.	Magnetic Magnetite (Fe ₃ O ₄) Nanoparticles Synthesis and Application for Lead (Pb ²⁺) and Chromium (Cr ⁶⁺) Removal from Water	2016	566
4	Q Tian et al.	Sub-10 nm Fe ₃ O ₄ @Cu ₂ -xS Core–Shell Nanoparticles for Dual-Modal Imaging and Photothermal Therapy	2013	554
5	Y Ren et al.	Magnetic EDTA-Modified Chitosan/SiO ₂ /Fe ₃ O ₄ Adsorbent: Preparation, characterization, and Application in Heavy Metal Adsorption	2013	490
6	L Feng et al.	Superparamagnetic High-surface-area Fe ₃ O ₄ Nanoparticles as Adsorbents for Arsenic Removal	2012	467
7	C Tan et al.	Radical induced degradation of acetaminophen with Fe ₃ O ₄ magnetic nanoparticles as heterogeneous activator of peroxymonosulfate	2014	401
8	H Wang et al.	Facile Synthesis of Polypyrrole Decorated Reduced Graphene Oxide - Fe ₃ O ₄ Magnetic Composites and its Application for the Cr (VI) Removal	2015	358
9	M Kumari et al.	Heavy metals [chromium (VI) and lead (II)] removal from water using mesoporous magnetite (Fe ₃ O ₄) nanospheres	2015	339
10	S Zhang et al.	Thiol modified Fe ₃ O ₄ @ SiO ₂ as a robust, high effective, and recycling magnetic sorbent for mercury removal	2013	335
11	A Banerjee et al.	MOF derived porous carbon– Fe ₃ O ₄ nanocomposite as a high performance, recyclable environmental superadsorbent	2012	292
12	T Zhang et al.	Synthesis of Fe ₃ O ₄ @ ZIF-8 magnetic core–shell microspheres and their potential application in a capillary microreactor	2013	280
13	Y Tan et al.	High efficient removal of Pb (II) by amino-functionalized Fe ₃ O ₄ magnetic nano-particles	2012	274
14	A Kumar et al.	Quaternary magnetic BiOCl/g-C ₃ N ₄ /Cu ₂ O/ Fe ₃ O ₄ nano-junction for visible light and solar powered degradation of sulfamethoxazole from aqueous environment	2018	267
15	Y Liu et al.	Study on the adsorption of Cu (II) by EDTA functionalized Fe ₃ O ₄ magnetic nano-particles	2013	264
16	RB Yang et al.	Synthesis and characterization of Fe ₃ O ₄ /polypyrrole/carbon nanotube composites with tunable microwave absorption properties: role of carbon nanotube and ...	2016	251
17	J Zhang et al.	Pb (II) Removal of Fe ₃ O ₄ @ SiO ₂ -NH ₂ Core-shell Nanomaterials Prepared Via a Controllable Sol-gel Process	2013	249
18	Y Chen et al.	Synthesis of porous hollow Fe ₃ O ₄ beads and their applications in lithium ion batteries	2012	249
19	M Sheikholeslami et al.	Effect of space dependent magnetic field on free convection of Fe ₃ O ₄ –water nanofluid	2015	242
20	YP Yew et al.	Green Biosynthesis of Superparamagnetic Magnetite (Fe ₃ O ₄) Nanoparticles and Biomedical Applications in Targeted Anticancer Drug Delivery System: A review	2020	242

of VOSviewer is intended to obtain visualization data and trend development data using bibliometric maps.

RESULTS AND DISCUSSIONS

Publication Data Search Results

Article data collection was carried out using Publish or Perish software. The software provides several choices of places to search for article data, including Crossref, Google Scholar, Google Scholar Profile, PubMed, OpenAlex, Scopus, Semantic Scholar, and Web of Science. However, in this study, the search for article data is processed through the Google Scholar database because it is a free data source, in contrast to Scopus which cannot be accessed freely. The first way to use Publish or Perish software is to choose a place to search for article data (in this case we choose Google Scholar), then enter keywords that are relevant to the research topic to be searched, and don't forget to also enter the distance between the years of the research. The article search results show that there are 998 articles indexed by Google Scholar with the categories of article titles, abstracts, and keywords in the period 2012 to 2022. The article data is then processed in the Microsoft Excel application and displays article results consisting of the number of citations, author names, article title, year of publication, source, publisher, article link, and citation link. Some examples of article data used in the analysis of the VOSviewer software in this study can be seen in Table 1. The sample used was 20 articles with the highest number of citations. In this study, there are 213925 total citations from all articles; 21392,50 the number of citations per year; 214.35 number of citations per article; 4,17 author average per article; all articles have an h-index of 236 and a g-index of 374.

Publication Development in the Field of Fe₃O₄ Nanoparticles

Data on publication developments in the field of Fe₃O₄ nanoparticles indexed by Google Scholar can be seen in table 2. Based on the data in Table 2, it can be seen that publication on Fe₃O₄ nanoparticles has increased and decreased every year. The number of publications of ferrous ferric oxide (Fe₃O₄) in 2012-2013 increased by 1 publication (92 publications to 93 publications). Then in 2014 there was a decrease in 2 publications (93 publications to 91 publications). In 2015, the number of publications increased by 15 articles from the previous year (91 publications to 106 publications). In 2016 there was another decrease of 6 publications from the previous year (106 publications to 100 publications). The largest increase in publications occurred in 2017 and 2018 with 110 and 109 publications. In the last 3 years there has been a drastic decline, namely in 2020 as many as 96 publications, 2021 as many as 73 publications, and 2022 as many as 27 publications allegedly due to the covid-19 pandemic so that research activities are also reduced. The development of Fe₃O₄ nanoparticle research is quite volatile which can be seen in Figure 1. These data indicate that the popularity of Fe₃O₄ nanoparticle research is relatively unstable and interest in Fe₃O₄ nanoparticles has decreased since the pandemic, which is likely that researchers will focus more on the search for drugs and vaccines.

Table 2 Development of Fe₃O₄ Nanoparticles Research

Year of Publication	Number of Publication
2012	92,0
2013	93,0
2014	91,0
2015	106,0
2016	100,0
2017	110,0
2018	109,0
2019	102,0
2020	96,0
2021	73,0
2022	27,0
Total	999,0
Average	90,8

According to previous research on the development of Fe₃O₄ nanoparticle production research conducted from 2017 to 2021, it showed quite a lot of publications every year, but the same as this study, the increase and decrease were not stable. From 2017 to 2019 the number of publications related to the production of Fe₃O₄ nanoparticles continued to increase respectively (190, 207, and 221 articles), but from 2020 to 2021 it continued to decrease (from 204 to 172 articles) [7].

Visualization of Fe₃O₄ Nanoparticles Topic Area Using VOSviewer

The two main objectives of bibliometric analysis are to look at research performance to conduct research and publications of individuals and institutions and to map science which aims to reveal the structure and dynamics of a topic of study. As for what is used in this study is the analysis of knowledge mapping, one of which we can use word analysis together to explore the relationship that exists between one topic and another in a particular field using vosviewer software.

Before viewing the visualization of research results, first set the minimum and maximum number of occurrences of a term. In this study, 5 minimum quantities and 276 maximum quantities were used. If there are terms that are considered irrelevant to the research topic, they can be omitted. Furthermore, the article data is mapped computationally using VOSviewer software. The results of computational mapping on bibliometric analysis of ferrous ferric oxide (Fe₃O₄) nanoparticles found 276 items but there were 2 items that were irrelevant, so the items used were 274 items. Each of these items has been divided into 9 clusters, namely:

- (i) Cluster 1 has 45 items, and marked in red, the 45 items are acrylic acid, average size, cell, chemical composition, chemical structure, co precipitation, construction, dls, drug delivery, evaluation, experimental study, facile fabrication, Fe₃O₄ magnetic nanoparticle, Fe₃O₄ mnp, Fe₃O₄ nanoparticle, Fe₃O₄ np, Fe₃O₄ SiO₂

- nanoparticle, fig, fourier, FTIR, high purity, magnetite nanoparticle, mean diameter, metal ion, morphology, nanoparticle, particle size distribution, peg, poly, poly synthesis, reusable catalyst, room temperature, sample, sem image, spectroscopy, stability, tem, tem image, value, x ray diffraction, xps, xrd, xrd pattern, and zeta potential.
- (ii) Cluster 2 has 41 items, and marked in green, the 41 items are agent, amount, aqueous solution, Au nanoparticle, chemical adsorption, chemical coprecipitation, chemical modification, chemical precipitation, chemistry, comparison, core shell nanoparticle, degradation, dielectric property, effective removal, effectiveness, efficient adsorbent, functionalization, green chemistry, ion exchange, kinetic, low cost, methylene, magnetic iron oxide nanoparticle, magnetic nanoparticle, nano Fe₃O₄, nanocatalyst, optimization, organic dye, present work, range, recoverable catalyst, removal, research, simultaneous removal, study, sulfonic acid group, surface area, time, wastewater, and water.
 - (iii) Cluster 3 has 41 items, and marked in blue, the 41 items are aggregation, analytical grade, catalytic activity, catalytic application, chemical precipitation method, chemical reaction, chemical reagent, chemical reduction, detection, determination, electrochemical sensor, electrode, enhancement, experiment, fabrication, Fe₃O₄, particle, further purification, glassy carbon electrode, graphene oxide, growth, hybrid, lithium ion battery, magnetic nanocomposite, nanocomposite, nitrophenol, order, oxidation, performance, reduction, rgo, sensor, separation, silver, simple, SiO₂, solution, structure, teos, use, work, and ZnO.
 - (iv) Cluster 4 has 28 items, and marked in yellow, the 28 items are aqueous medium, catalyst, chemical bond, chemical coprecipitation method, chromium, coprecipitation method, copper, core, core shell, coreshell, efficient removal, enzyme, facile synthesis, Fe₃O₄ SiO₂, FeCl, first time, immobilization, magnetic Fe, magnetite, magnetite particle, mnp, nano Fe, polymer, preparation, process, silica, SiO, and synthesis.
 - (v) Cluster 5 has 28 items, and marked in purple, the 28 items are addition, adsorbent, adsorption, carbon nanotube, combination, double hydroxide, EDTA, Fe₂O₃, Fe₃O₄, Fe₃O₄SiO₂, figure, group, high chemical stability, improvement, increase, ion, iron, iron oxide, magnetic Fe₃O₄ nanoparticle, magnetic nanoparticle, methylene blue, nano particle, oxygen, particle size, potential, silver nanoparticle, surface, and term.
 - (vi) Cluster 6 has 25 items, and marked in light blue, the 25 items are carbon, coating, composite, composition, decomposition, emulsion, formation, functional group, impact, interaction, magnetic particle, magnetic property, mechanism, modification, mos, number, particle, reaction, role, series, shell, size, surface chemistry, surface modification, and type.
 - (vii) Cluster 7 has 25 items, and marked in orange, the 25 items are analysis, article, behavior, chemical process, concentration, diameter, effect, ethylene glycol, flow, function, heat transfer, influence, investigation, magnetic field, mixture, modeling, nano material, nanofluid, nanoparticle size, paper, presence, property, shape, temperature, and water nanofluid.
 - (viii) Cluster 8 has 21 items, and marked in brown, the 21 items are arsenic, attention, biocompatibility, biomedical application, chain, chemical, chemical property, chemical stability, density, development, drug delivery system, extraction, field, graphene, nanomaterial, nanotechnology, physical property, potential application, preconcentration, recent year, and water sample.
 - (ix) Cluster 9 has 20 items, and marked in pink, the 20 items are acid, antibacterial

activity, application, characterization, chemical co precipitation method, chemical method, chitosan, doxorubicin, Fe₃O₄ nano particle, green synthesis, iron oxide nanoparticle, magnetic Fe₃O₄, nano, photocatalytic activity, photocatalytic degradation, physical method, plant, present study, tio, and treatment.

The terms indicated in each cluster have a relationship with each other. Each cluster is displayed with a different color. In network visualization, items are represented by their labels and by default also by circles. The size of the label and circle of an item is determined by the weight of the item [27]. The larger the label and circle of items, the higher the weight of an item [25]. Some items in the label that are not displayed are intended to avoid overlapping between labels. An example of the network visualization of Fe₃O₄ nanoparticles is shown in Figure 2. The network visualization also shows that each cluster contains a line of items that represent links. The maximum line of items that can be displayed in the VOSviewer visualization is 1000 links which are considered the most powerful among other items. The distance between journals from one another in the VOSviewer visualization more or less shows the journal's relationship in terms of co-citation. So it can be concluded that the strength of the relationship of a journal is seen from the closeness of each journal. The closer the two journals are to each other, the stronger the relationship. The strongest citation links between journals are also represented by lines [17].

In density visualization, each item is represented by its label in the same way as in network visualization. Each point in the density visualization has a color that indicates the density of the object at that point. By default, the displayed colors are blue, green, and yellow. The color indicates the dominance of a term that appears. The greater the number of items around the dot, the higher the weight of the surrounding items indicated in yellow. On the other hand, the smaller the number of items around a point, the lower the weight of the surrounding items indicated in blue [17, 27, 29, 30]. The yellow color indicates that a lot of research has been done regarding the term. On the other hand, if the color of the indicated term begins to fade and becomes a blue color, then the number of studies on the term is small. Based on Figure 3, it can be seen that research related to the term Fe₃O₄, Fe₃O₄ nanoparticles, nanoparticles, particles, nanocomposites, composites, properties, and synthesis has a high number of studies. An example of the density visualization of Fe₃O₄ nanoparticles is shown in Figure 3.

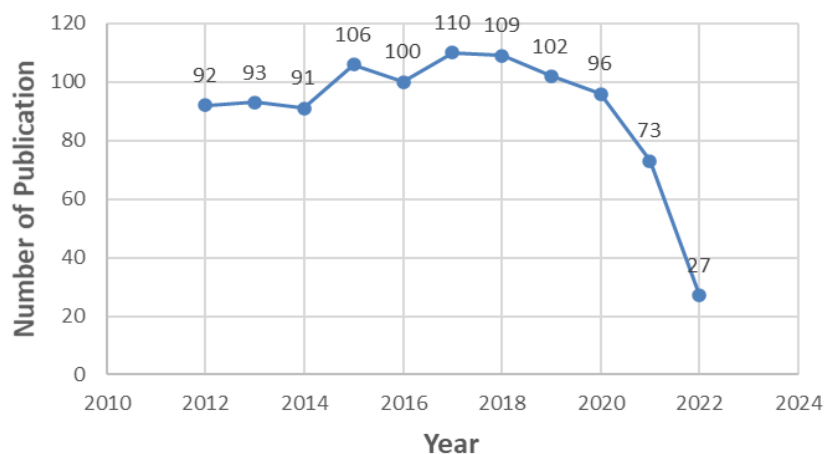


Figure 1 Level of Development in Fe₃O₄ Nanoparticle Research

occurrences (see Figure 6). The term "Fe₃O₄" was associated with 237 links, a total link strength of 1297, and 222 occurrences (see Figure 7).

The relationship network of Fe₃O₄ nanoparticles with other terms, namely nanoparticle, nano, synthesis, particle size, removal, acid, size, influence, role, catalyst, process, characterization, agent, ion, fabrication, potential application, value, and evaluation is shown in Figure 5. Figure 6 shows the network of relationships between the term nanoparticles and other terms, namely Fe₃O₄ nanoparticle, nano, nanofluid, shape, average size, particle size, synthesis, removal, acid, field, size, x ray diffraction, influence, formation, Fe₂O₃, emulsion, sample, role, catalyst, process, characterization, agent, ion, fabrication, value, catalytic application, chemical reduction, oxidation, hybrid, TEM, XRD, SiO, SiO₂, and evaluation. While Figure 7 shows the relationship network of Fe₃O₄ with other terms, namely density, nanofluid, temperature, Fe₂O₃, size, particle size, magnetic particle, Fe₃O₄ nanoparticle, figure, potential, synthesis, removal, preparation, acid, sample, characterization, value, XRD, agent, ion, nano, oxidation, reduction, core, Fe, and catalyst. From these data, it can be seen that the field of Fe₃O₄ nanoparticles tends to have a high degree of relevance and is often associated with various terms. The terms that most often appear and relate to Fe₃O₄ nanoparticles are related to synthesis, characterization, preparation, catalyst, and application processes as seen in previous studies that need to be developed [25, 26, 27]. Therefore, it can be concluded that the field of Fe₃O₄ nanoparticles is possible to study and can be associated with other terms that will have a higher impact on the novelty of the research.

CONCLUSIONS

Fe₃O₄ is one of the iron oxides that shows the strongest magnetic power compared to other iron oxides, so it is widely used in various fields, including as a heavy metal binder. The characteristics of Fe₃O₄ nanoparticles include high saturation magnetization value, soft magnetism, small coercive field, and low anisotropy value, as well as having superparamagnetic properties. This study aims to analyze computational bibliometric mapping using VOSviewer software on Fe₃O₄ nanoparticles. The results of the visualization related to ferrosferric oxide (Fe₃O₄) nanoparticles show 274 interrelated terms and these terms can be divided into 9 clusters. Then for the results of the analysis of research developments related to ferrosferric oxide (Fe₃O₄) nanoparticles showing an increase and decrease from 2012 to 2019. The largest increase in publications occurred in 2017 and 2018 with the number of publications being 110 and 109. In the last 3 years there has been a drastic decline, namely in 2020 there are 96 publications, in 2021 as many as 73 publications, and 2022 as many as 27 publications which are thought to be due to the COVID-19 pandemic so that research activities are also reduced. These data indicate that research on ferrosferric oxide (Fe₃O₄) nanoparticles is relatively unstable and interest in ferrosferric oxide (Fe₃O₄) nanoparticles has decreased. Therefore, the results of this study are expected to be a reference for further research so that the topic of nanoparticles, especially the terms that appear most often, are those regarding synthesis, characterization, preparation, catalysts, and the application process of ferrous ferric oxide (Fe₃O₄) nanoparticles can continue to development.

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