Bibliometric Analysis of the Synthesis of Nanocatalyst (1999–2018)

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Abstract. Taking the Web of Science database as the data source, and taking 3047 SCI documents published in the field of nanocatalyst synthesis published between 1999 and 2018 as the analysis objects, the annual publication volume, space-time distribution, research institutions, and authors of the relevant documents were analyzed. Use the visualization software VOSviewer generated literature keywords co-occurrence clustering view, keywords co-occurrence chronology view, and keywords co-occurrence clustering density view, analysis of the research in the field of countries are China and Iran. The research focus is mainly on the design and synthesis of new nanocatalysts, so that the morphology and particle size of nanoparticles can be well controlled, so as to improve the catalytic activity and selectivity of nanocatalysts, and to study the catalytic reaction mechanism. The research frontier mainly focuses on the efficient and green synthesis of nanocatalysts, especially the recycling and reuse of nanocatalysts. The development and utilization of new nanocomposites and nanophotocatalysts with photocatalytic properties, as well as the performance research of other sizes of nanomaterials such as nanoclusters, nanowires, and nanosheets.

1. Introduction

Cleaner production is proposed by the United Nations Environment Programme's Industrial and Environmental Planning Action Center. The key to improving the environment, solving pollution and achieving sustainable development is the adoption of new materials and technologies. With the expansion of nanomaterials and nanotechnology to various fields, the research and application of nanocatalysts in the fields of chemical industry and petrochemical industry are rapidly developing [1]. With the decrease of the particle size of the nano-material, the surface smoothness is poor, and uneven atomic steps are formed, which increases the contact surface of the chemical reaction. These properties exactly meet the particle size, surface area, electronic properties, adsorption properties, and catalytic reaction properties required by nano coarse materials and auxiliary materials [2]. The catalyst in industrial production should have the characteristics of large surface area, good stability and high activity. Nanomaterials just meet these characteristics, and the catalysts prepared by nanomaterials have higher selectivity in catalytic efficiency than conventional catalysts.

In recent years, with the in-depth research on the synthesis of nanocatalysts, more and more researchers have introduced ultrasonic chemistry into photocatalytic technology, and the number of papers published in this field has also increased significantly. The rapid increase in the number of papers makes it difficult to have a comprehensive understanding of the research on nanocatalyst
synthesis. The purpose of this paper is to analyze the main research force, research basis, research hot spot and frontier of nanocatalysts synthesis by using bibliometric analysis and visualization software.

2. Data sources and research methods

In the core collection database of Web of Science, the retrieval condition is "(Topic = (nanoparticle*)) AND Topic = (Nanocatalyst*)) AND Topic = (synthesis*)"; Literature type = (ARTICLE OR PROCEEDINGS PAPER OR REVIEW); The retrieval time span is 1985-2018; Indexes: SCI-Expanded, SSCI, A & HCI, CPCI-S, ESCI, CCR-Expanded, IC"; The bibliography to be downloaded for each article includes the author, title, source publication, and cited references. The downloaded documents are called citing articles, which represent the forefront of research, and the references of these citing articles are called cited articles, which represent the basis of the research [3-4].

Bibliometric analysis and clustering methods were used to classify statistics based on the publication time, author, and subject classification of the literature, and the development trend of nanocatalysts was analyzed by indicators such as the number of papers, publication time, research institutions and teams, and subject distribution. And use VOSviewer software to mine the literature information of the selected literature data. By analyzing the high-frequency keywords, the research hotspots of nanocatalysts are visually displayed with visualized images.

3. Results

After screening, a total of 3,047 articles were obtained. From the distribution of nano-catalyst synthetic publications in the WOS database, it can be seen that the largest number of publications were 663 (21.759%) in 2018 and the lowest number was 1 (0.033%) in 1999. From 1999 to 2008, the number of published papers increased year by year (see Figure 1). As can be seen from figure 1, research on synthesis of nanocatalysts started in 1999. From 1999 to 2006, the research on the synthesis of nanocatalysts was at the initial stage, with 22 papers published in 6 years, accounting for 0.723% of the total volume. From 2007 to 2010, this period was the founding stage of the research, 142 papers were published during the four years, accounting for 4.661% of the total volume. From 2011 to 2018, the number of papers published increased significantly each year. This phenomenon indicates that the research on the synthesis of nanocatalysts has attracted more and more attention of researchers in recent years, and more and more results have been achieved in this regard.

![Figure 1. Distribution of the number of articles published between 1998 and 2018.](image-url)

3.1. Citation analysis

After setting the search strategy and screening, a total of 3,047 citations were obtained. Through citation analysis, the value of h-index is 98; the average number of citations per item is 21.12; the total
The number of cited references was 41,757, and 39,679 after removing self-cited references. The article with the highest frequency of citation is the article titled Thermally stable Pt / mesoporous silica core-shell nanocatalysts for high-temperature reactions published in the journal Nature Materials in 2009 [5]. It has been cited 921 times. Table 1 lists the names of the top 10 most cited articles.

Table 1. Table of top 10 most cited articles.

| No. | Article                                                                                                                                  | Year  | Journal                                                | NO. of citations |
|-----|-----------------------------------------------------------------------------------------------------------------------------------------|-------|--------------------------------------------------------|------------------|
| 1   | Thermally stable Pt/mesoporous silica core-shell nanocatalysts for high-temperature reactions [5]                                     | 2009  | Nature Materials                                       | 921              |
| 2   | Magnetically Separable Nanocatalysts: Bridges between Homogeneous and Heterogeneous Catalysis [6]                                      | 2010  | Angewandte chemie-international Edition                 | 906              |
| 3   | Synthesis and characterization of nitrogen-doped TiO₂ nanophotocatalyst with high visible light activity [7]                          | 2007  | Journal of Physical Chemistry C                        | 763              |
| 4   | Nano-magnetite (Fe₃O₄) as a support for recyclable catalysts in the development of sustainable methodologies [8]                      | 2013  | Chemical Society Reviews                               | 647              |
| 5   | Synthesis of Clean and Well-Dispersive Pd Nanoparticles with Excellent Electrocatalytic Property on Graphene Oxide [9]               | 2011  | Journal of the American Chemical Society               | 635              |
| 6   | Tuning Nanoparticle Catalysis for the Oxygen Reduction Reaction [10]                                                                     | 2013  | Angewandte chemie-international Edition                 | 554              |
| 7   | Synthesis and catalytic properties of metal nanoparticles: Size, shape, support, composition, and oxidation state effects [11]       | 2010  | Thin Solid Films                                       | 554              |
| 8   | Atomically Precise Gold Nanoclusters as New Model Catalysts [12]                                                                          | 2013  | Accounts of Chemical Research                          | 492              |
| 9   | Nanocatalysts for Suzuki cross-coupling reactions [13]                                                                                   | 2011  | Chemical Society Reviews                               | 482              |
| 10  | Facile Synthesis of Surfactant-Free Au Cluster/Graphene Hybrids for High-Performance Oxygen Reduction Reaction [14]                 | 2012  | Acs Nano                                               | 411              |

3.2. Country analysis
Between 1998 and 2018, there were 11 countries published at least 50 published papers. The top country is Iran, with 893 papers (29.308%). The second-ranked country is China, with 818 papers published (26.846%). Only these two countries have published more than 500 papers, which is far more than other countries. In addition, the countries ranking 3-11 are: India 383 (12.570%), USA 298 (9.780%), South Korea 193 (6.334%), Japan 89 (2.921%), France 82 (2.691%), Germany 70 (2.297%), Spain 67 (2.199%), Turkey 60 (1.969%), Canada 54 (1.772%).

Visualization of international collaboration was created using VOSviewer technique. In the network visualization map, the strength of collaboration between countries is expressed by the thickness of the line between any two countries. Figure 2 shows inter-country collaboration between various developed and developing countries. The thickness of the connecting lines represents the extent of collaboration between any two countries. As can be seen from the figure, there are many
academic exchanges and cooperation in the field of nanocatalyst research in various countries, among which China and the United States have the most frequent cooperation.

![Figure 2](image-url)  
*Figure 2. Network visualization of inter-country collaborations among countries. Links represent the strength of collaboration.*

### 3.3. Institutions / organizations

From 1998 to 2018, there were 8 research institutions in Institutions / organizations with at least 50 papers published. Ranked first was Chinese Academy of Sciences with 206 papers (6.745%). Ranked second is IsLamic Azad University with 167 posts (5.468%). In addition, the research institutions ranked 3-8 are: Payaya Noor University 94 (3.078%), University Kashan 74 (2.423%), Centre national de al recherche Scientifique CNRS 65 (2.128%), United States Department of Energy DOE 64 (2.096%), Iran University Science Technology 61 (1.997%), Council of Scientific Industrial Research CSIR India 55 (1.801%).

Four of these research institutes belong to Iran, one to China, one to India, one to the United States, and one to France. The distribution of the publications of scientific research institutions was consistent with the distribution of the publications of countries, which further indicated that all countries in the world had invested certain human and material resources in the field of nanocatalysts, while Chinese Academy of Sciences and IsLamic Azad University were the main research institutions engaged in the field.

### 3.4. Journals and authors

Eight journals have published at least 50 articles for nanocatalyst research. The top-ranked journal was 223 articles (7.302%) published by Rsc Advances, which belongs to Q2 in the JCR division and IF is 3.096. In the second place, 137 (4.486%) published in the Journal of Applied Organometallic Chemistry, which belongs to Q1 in the JCR section, and IF is 2.612. Ranked third was 75 articles (2.456%) published by the New Journal of Chemistry, which belongs to Q2 in the JCR section and IF is 3.181. Ranked fourth was 66 articles (2.161%) published by the International Journal of Hydrogen Energy, which belongs to Q2 in the JCR section and IF is 4.064. Ranked fifth was 61 articles (1.997%) published by the Journal of Materials Chemistry A, which belongs to Q1 in the JCR section and IF is 9.531. Ranked sixth was 58 articles (1.904%) published by Nanoscale journal, which belongs to Q1 in the JCR section and IF is 7.713. In seventh place, 51 articles (1.674%) were published by the journal
Acs Applied Materials Interfaces, which belongs to Q1 in the JCR section and IF is 8.284. Tied for seventh place were the 51 articles (1.674%) on the Journal of Chemical Intermediates, which belongs to Q3 in the JCR section and IF is 1.466. From the research fields involved in the journal, the research on nanocatalyst synthesis mainly involves the fields of chemistry, materials science, physics, energy and fuel, electrochemistry, environmental ecology, engineering, and polymer materials.

Maleki, Ali at Iran University Science & Technology, Iran, the department of chemistry ranked the same third with 53 (1.735%) articles. Veisi, Hojat at Payame Noor University, Iran, the department of chemistry ranked second with 51 (1.670%) articles. Ghorbani-Choghamarani, Arash at Ilam University, Iran, the department of chemistry ranked third with 36 (1.179%) articles. Zhang Ya-wen at Peking University, China, state key laboratory rare earth matel chem & application ranked forth with 33 (1.081%) articles.

3.5. Co-occurrence of keywords analysis

3.5.1. Keyword Co-occurrence Cluster View. VOSviewer software was used to generate a keyword co-occurrence clustering view in the field of nanocatalyst synthesis. A total of 193 keywords with a frequency of ≥ 30 were selected from 9751 keywords, and a co-occurrence analysis was performed on these 193 keywords, as shown in Figure 3.

![Figure 3. VOSviewer keyword co-occurrence clustering view.](image)

In Figure 3, the node area and font size depend on the weight value of the keyword. The greater the weight value is, the more times the keyword appears, and the larger the corresponding node and font will be; the line between nodes indicates that a keyword appears in common with another keyword. The thickness of the connection line indicates the co-occurrence strength between the two keywords. The thickness of the connection line is proportional to the co-occurrence strength, which means that the thicker the connection line, the more times the two keywords co-occur.

From the analysis in Figure 3, three clusters can be obtained. The topics are summarized for each cluster, and the keywords in each cluster are listed (as shown in Table 2). Name each category with the iconic keywords in each category.
3.5.2. Chronology view of keywords co-occurrence.

Table 2. Key words of research topics.

| cluster | topic       | keywords                                                                 |
|---------|-------------|--------------------------------------------------------------------------|
| #1      | nanoparticles | Facile synthesis, hydrogenation, catalysts, carbon, graphe, performance, electrooxidation, oxygen reduction reaction, shape-controlled synthesis et al |
| #2      | nanocatalyst | One-pot synthesis, heterogeneous catalyst, solvent-free condition, recyclable, efficient, derivatives, water, acid, sillica, Fe₃O₄, magnetic, condensation, 3-component synthesis, multicomponent reaction, inhibitors, |
| #3      | nanostructures | Gold nanoparticles, reduction, oxide, surface, silver nanoparticles, growth, metal nanoparticles, aqueous-solution, composite, photo-catalysis, visible-light, degradation, adsorption, 4-nitrophenol, biosynthesis, immobilization et al |

VOSviewer can also analyze the co-occurrence year between keywords. Through the co-occurrence chronology of keywords, the first co-occurrence time between keywords can be clearly displayed, which will help us understand the research in the field of nanocatalyst Hot spots and development evolution.

The co-occurrence chronology view is shown in Figure 4. The color of the line between the keywords in the figure indicates the first co-occurrence time of the two. The thicker the line is, the greater the intensity of the two co-occurrences, and the greater the number of co-occurrence between the two keywords.

Figure 4. The co-occurrence chronology view of keywords.

It can be seen that nanocatalyst first appeared in 2015, which fully shows that this field is a new research field. Although this concept appeared relatively late, but because of its rapid development has formed some special relationship with multiple science fields, the reasons for this are: (1) It can be seen from time that before nanocatalysts were proposed, clusters have been showing a different degrees of connection, which indicates that researchers in various disciplines have a certain basis for research between clusters. The discovery of the nanoparticles first began in May 2014. Researchers tested all aspects of their properties and found that they have natural enzyme-like activity. (2) After discovering the catalytic activity of nanoparticles, researchers have focused on the comparison with
natural enzymes and the performance of nanocatalysts since 2015. Studies have found that nanocatalysts have significant advantages: low cost, easy to produce in large scale, little environmental impact, high stability, and long-term storage. The catalytic activity of the nanocatalyst is closely related to its size, shape, structure, and composition; its large surface area can be used for further modification and biological coupling. Nanocatalysts can simulate a variety of natural enzymes, such as catalase, oxidase, peroxidase, superoxide dismutase, nuclease and so on. (3) Since 2016, the research focus has been extended to the green synthesis of nano-catalysts, such as the one-pot synthesis method. A new type of nanocatalyst is designed through experiments and theoretical calculations, so that the morphology and particle size of the nanoparticles can be well controlled. The research on the improvement of catalytic activity and selectivity of nanocatalysts and the mechanism of catalytic reactions are the hotspots of current research. The applied nanomaterials are also more extensive, such as metal oxides, metal nanoparticles, graphene derivatives, composite nanomaterials, etc. While considering how to improve the catalytic performance of nano-catalysts, the recyclability of catalysts should be taken into account to make the application of nanocatalysts greener and environmentally friendly.

3.5.3. Clustering density view of keyword co-occurrence. In this view, each node represents a keyword, and the density of the node will change with the change of the surrounding keyword values. In the center of the node density is higher, the deeper the color, the more bright, as the research focus areas. The lower the density of the nodes at the edges, the closer their colors are to blue, indicating that the research topic is not hot.

![Figure 5. Clustering density view of keyword co-occurrence.](image)

According to figure 5, it is inferred that the yellow color in the center area is the current research hotspot, the related researches are as follows: nanocatalyst performance, nanostructures, one-pot synthesis, heterogeneous catalyst, facile synthesis, green synthesis, derivative, silver nanoparticles, palladium nanoparticles, fuel-cells, pd nanoparticles, silver nanoparticles. The blue area at the edge is the research frontier, and the related researches are as follows: shape-controlled synthesis, efficient synthesis, green condensation, cross-coupling reactions, alloy nanoparticles, nanocomposites, biosynthesis, nanosheets, nanowires, photocatalytic degradation.
4. Conclusion
(1) From 1999 to 2018, the number of literatures published in the field of nanocatalyst synthesis has been increasing year by year, especially after 2010, the increase has been obvious. This phenomenon indicates that the field has received more and more attention. It can be seen from the distribution of the issuing countries and institutions that the research strength in this field is mainly concentrated in China and Iran.

(2) The current international research hotspots in the field of nanocatalyst synthesis are mainly the design and synthesis of new nanocatalysts, so that the morphology and particle size of nanoparticles can be well controlled, so as to improve the catalytic activity and selectivity of nanocatalysts and study their catalytic reaction mechanism. The research frontier mainly focuses on the efficient and green synthesis of nanocatalysts, especially the recycling and reuse of nanocatalysts. The development and utilization of new nanocomposites and nanophotocatalysts with photocatalytic properties, as well as the performance research of other sizes of nanomaterials such as nanoclusters, nanowires, and nanosheets.

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