Visual analysis on coal adsorption study

Yanni Zhang[1a*], Jingjing Yang[1b*], Yunchao Hou[1c*], Pan Shu[1d*]

[1]College of Safety Science and Engineering, Xi'an University of Science and Technology, Xi'an Shaanxi 710054, China

Abstract—Coal spontaneous combustion is one of the main disasters that threaten mine safety production., and coal adsorption characteristics is the main cause of coal spontaneous combustion. Therefore, a lot of researchers have begun to pay close attention to the field of coal adsorption research to prevent coal spontaneous combustion. Based on bibliometrics, this paper analyzes the number of published papers, journal sources, high-yield authors, institutions and research hotspots on coal adsorption in the SCI database of Web of Science platform, and makes a visual analysis using Citespace software. The research shows that the number of papers published in the field has been on the rise in recent years, and China's influence in this field has gradually strengthened.The most in-depth research institutions and journals in the field of coal adsorption are China University of Mining and Technology and FUEL, respectively.In terms of research content, the coal pore structure and multi-factor coupling affect on coal adsorption capacity will be a research hotspot in this field in the future.

1. Introduction

Coal is the main component of China's energy reserves, accounting for about 62% of the energy structure[1,2]. As the amount of coal mining increases, the problem of coal mine safety production is becoming increasingly serious, in which coal spontaneous combustion is one of the most major disasters in coal mine safety production[3]. Coal spontaneous combustion not only causes a lot of waste of resources, but also threatens the safety and health of underground workers. Research shows that coal spontaneous combustion is due to the coal contact with the air, and then physical adsorption with oxygen in the air, and then release physical adsorption heat, which provides energy for the reaction of active structures in coal, and then coal reacts with oxygen to release heat, heat accumulation caused the coal spontaneous combustion[4,5]. Therefore, coal adsorption reaction is the first key step in the process of coal spontaneous combustion. It is of great significance to research the coal adsorption characteristics to prevent coal spontaneous combustion. Although researchers have done numerous studies in the coal adsorption field in recent years, no comprehensive bibliometric analysis of the published studies has been carried out. In this paper, the historical context of coal adsorption research is summarized by using the bibliometrics method, the literature and related tools of the Web of Science(WOS) core collection database. Based on Citespace software, this paper focuses on the literature related to coal adsorption in recent years. The authors, research institutions, journals, research hotspots and frontier changes are bibliometrically analyzed to analyse the research status and development trend of coal adsorption in the world, providing theoretical basis and reference for future research in this field.

2. Data sources and research methods

2.1 Data sources

This paper takes the WOS database as the data source, takes "adsorption" and "coal" as the title search terms, the language is set to "English", the document reduction type is "article", and the search time is all years (1985-2022). According to the database inclusion, the final retrieval time range was 2016-2022. After manual screening of literatures with less relevance to the topic, 561 articles were selected as English literature sample data.

2.2 Research methods

As a quantitative statistical analysis technology of literature metrology, is widely used to provide an overview of publications and to master the current state of research of a certain field[6,7]. Many software tools such as VOS Viewer, Bibexcel, HistCite, etc. can study the status of research of a certain field from the perspective of literature analysis. Citespace, as one of the most commonly used visualization software in

[a*]798850990@qq.com; [b*]1607916791@qq.com; [c*]1497233856@qq.com; [d*]514920531@qq.com

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bibliometrics, can comprehensively introduce the status of research and development trend in the future of a certain field by analyzing authors and keywords[8,9]. By using Citespace, Origin and other software to analyze the relevant literature on coal adsorption, this paper explores the status of research and development trend in the field of coal adsorption, and provides a theoretical basis for future research in the field.

3. Research status analysis

3.1 The paper presented quantitative analysis

By analyzing the number of publications in a field, the research level and development trend in this field can be understood to some extent. Figure 1 shows the distribution of published papers in the coal adsorption field from 2016 to 2022.

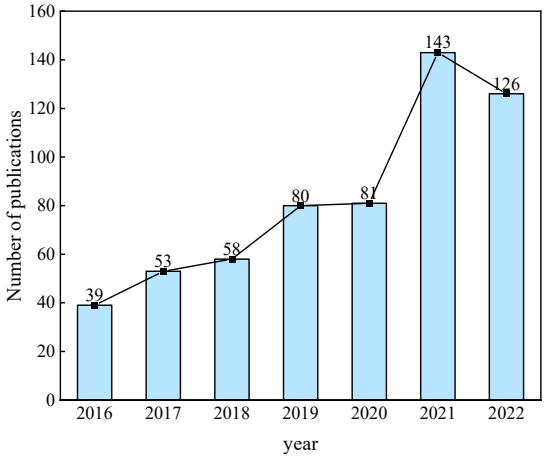

Fig.1 Publication distribution

According to Figure 1, 39 papers were published in the field of coal adsorption in 2016, and 143 papers were published in 2021, with an annual growth rate of 29.7%. Overall, the number of publications on coal adsorption showed an overall rising trend during 2016-2022, which can be divided into two stages: stable development period during 2016-2018 and vigorous development period during 2019-2022, and a surge phenomenon occurred in 2021. This phenomenon is connected with the increasing trend of global coal production in recent years. Coal spontaneous combustion disasters occur more and more frequently with the increase of coal mining, which makes coal adsorption research become the focus of global scholars. Moreover, China put forward the safe and efficient mining and clean and efficient intensive utilization of coal during the "Thirteenth Five-Year Plan" period, which also prompted Chinese scholars to invest a lot of research to prevent coal spontaneous combustion.

3.2 Distribution of published journals

Selecting the data for this paper and analyzing the distribution of relevant literature in the main journals of WOS can provide direction for literature collection and early knowledge accumulation in this field, and reflect the theoretical and practical value of the research field to a certain extent. According to the analysis of the obtained data, the literature on coal adsorption research has been published in 278 different journals from 2016 to 2022. Table 1 lists the top five journals, namely: Fuel, Energy & Fuels, Journal of Natural gas Science and Engineering, International Journal of Coal Geology and Journal of Geology Petroleum Science and Engineering. The total number of articles published in the above five journals is 176, accounting for 31.36% of the total publications, covering energy and fuels, ecology and environment, chemical engineering, geology and other disciplines.

Tab.1 Distribution of WOS coal adsorption research literature and journals

Journal title	Number of publications	Percentage/%	Influence factor	Journal topic
Fuel	61	10.87	5.578	Energy and fuel engineering
Energy & Fuels	55	9.80	3.421	Energy and fuel engineering
Journal of Natural Gas Science and Engineering	26	4.63	3.841	Energy and fuel engineering
International Journal of Coal Geology	17	3.03	5.692	Energy and fuel geology
Journal of Petroleum Science and Engineering	17	3.03	3.709	Science and Energy geology

Impact factors can usually be used to judge the influence of a journal. The greater the impact factor value in a certain field, the greater the research value and influence. As can be seen from Table 1, Fuel ranks first in the number of journals published, but its impact factor is not the highest. The journal with the highest impact factor is International Journal of Coal Geology, whose impact factor value is 5.692, 0.014 higher than Fuel. The research fields of International Journal of Coal Geology are fuel engineering and geology, and its articles have high quality and recognition in the field, but it is not the first choice journal in the coal adsorption field. Although Fuel is not the journal with the highest impact factor among the journals published in the coal adsorption field, it ranks the first in the number of articles published, which is widely concerned in the field of fuel engineering and it has important work for the research in the coal adsorption field.

3.3 Research institution and author distribution

By using Citespace software to draw the cooperative knowledge graph of high-yield authors, so as to analyze

the cooperative relationship between high-yield authors in the coal adsorption field. The bigger the node, the more the authors published. The thicker the connection between nodes, the closer the collaboration between authors.

Tab.2 Top 5 high-yield authors of WOS coal adsorption studies

Author	Research institution	Number of publications	Research direction
Yuanping Cheng	China University of Mining and Technology	15	Mine gas prevention and control, fire prevention
Zengchao Feng	Taiyuan University of Technology	12	Coal mine safety and rock mechanics mining
Dameng Liu	China University of Geosciences (Beijing)	10	Geological theory and evaluation technology of coalbed methane
Dong Zhao	Taiyuan University of Technology	10	Gas control
Dong Zhou	Taiyuan University of Technology	10	Coalbed methane extraction

Fig.2. Author statistics of high yield of WOS coal adsorption

As can be seen from Table 2, there are five authors with 10 or more publications. The author who had published the most articles in the coal adsorption field was Yuanping Cheng (15 articles from China University of Mining and Technology), followed by Zengchao Feng (12 articles from Taiyuan University of Technology), and Dameng Liu (10 articles from China University of Geosciences). The top five prolific authors were all from China. According to BP Statistical Yearbook of World Energy 2022[10], China, India and Indonesia are the top three countries in terms of global coal production in 2021, among which China's coal output accounts for 50.5% of the world's total output, ranking first in the world. The higher the coal production, the more frequent coal mine disasters, and coal spontaneous combustion is one of the most prominent coal mine disasters, so at present China's coal mine disaster is more serious, and coal spontaneous combustion prevention is the goal of Chinese scholars.

According to statistics, 262 authors have published papers related to coal adsorption research. According to Table 2 and Figure 2, the research directions that the authors focus on in the field of coal adsorption overlap somewhat, and the main research directions are gas prevention and coal bed methane mining. Figure 2 shows the cooperative relationship among authors in this field. The main researchers in the cooperative network are Yuanping Cheng and Zengchao Feng, and other scholars cooperate with one of these main researchers to form a close cooperative cluster, such as the authors group formed with Yuanping Cheng as the core, mainly research mine gas control; a group of authors formed with Zengchao Feng as the core, the main area of research is rock mechanical mining methods.

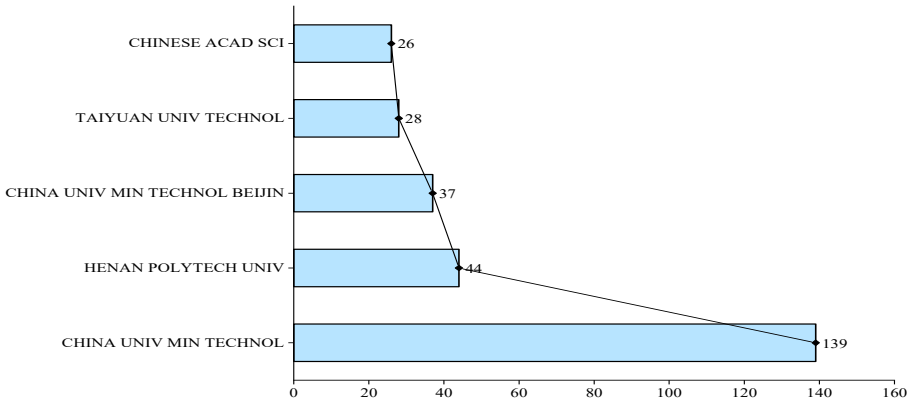

Fig.3 Statistical analysis of WOS coal adsorption research institutions

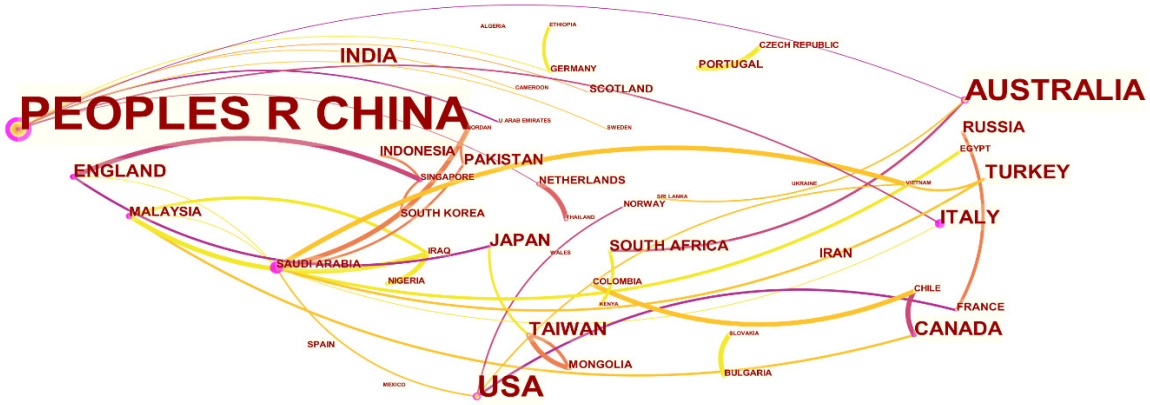

Fig.4 National statistical analysis of WOS coal adsorption studies

Based on the analysis of high-yield countries and research institutions in the field of coal adsorption, and the ranking of the top five research institutions, it can be found that a total of 51 countries have made achievements in this field, among which China, the United States and Australia are in the leading position. The cooperation among countries is relatively close, which jointly promotes the research in the coal adsorption field. China's research in the coal adsorption field occupies a large proportion, and the research institutions are mainly distributed in colleges and universities, which is connected with the academic team, academic exchanges and scientific research equipment of colleges and universities. Figure 3 shows that the two campuses of China Univ Min & Technol and China Univ Min & Technol Beijing have published a total of 169 papers, among which the Xuzhou campus has 134 papers, which is much higher than other research institutions, indicating that this institution is ina leading position in the field of coal adsorption research. It has great advantages and influence in the research of this field. Secondly, Henan Polytech Univ, Taiyuan Univ Technol and other research institutes have conducted extensive research centered on China Univ Min & Technol and have jointly promoted the development direction of the field. These data show that engineering colleges occupy a large proportion of the high-yield institutions in coal adsorption research and have significant research strength. It can be seen from Figure 3 and Figure 4 that the scientific research achievements in the field of coal adsorption in China occupy a major position, and the main research institutions correspond to the research scholars, and the Chinese scholars are the main force in this research field.

3.4 Keywords cluster analysis

Keywords are subject words that appear repeatedly within a document and can highly summarize the main content of the article. Therefore, counting the high-frequency keywords of all articles in a research field can to some extent, reveal the research focus in the field. Clustering analysis in Citespace means that keywords show the close and distant relationship between co-occurring keywords on the basis of co-occurrence network, and cluster according to their degree of close and distant relationship. Cluster number is inversely proportional to keyword frequency, that is, keyword frequency gradually decreases with the increase of cluster number. According to the clustering index analysis, the value of Modularity Q >0.3 indicates that the clustering structure is important, and the value of Silhouette S >0.5 indicates that the clustering is rational. If S>0.7, the clustering is reliable. Figure 5 shows the coupling network diagram of keywords clustering and drawing based on LLR algorithm, including 12 clusters. Figure 5 only lists 5 clusters with a high degree of clustering, and its Q value is 0.5091>0.3, S value is 0.7803>0.7. It shows that the structure of the map network module is remarkable and the clustering effect

is good and convincing. Based on the above analysis, through information screening, induction and sorting, it is concluded that the main research focus in the coal adsorption field can be divided into three categories: theoretical model of coal adsorption, influencing factors of coal adsorption and thermodynamic research of coal adsorption.

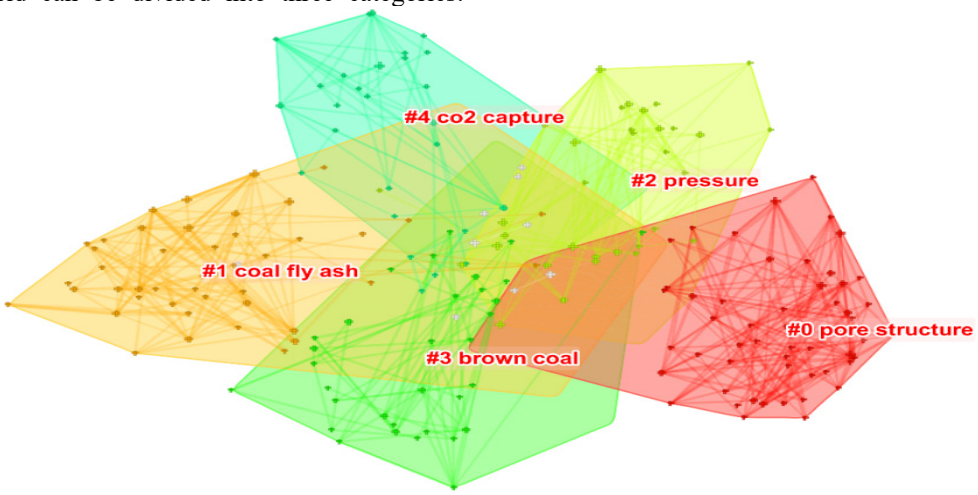

Fig.5 Keyword co-occurrence network clustering

(1) Theoretical model of coal adsorption. In recent years, various scholars in the field have studied the coal adsorption phenomenon and put forward a large number of theoretical models. Langmuir proposed a single molecule adsorption model based on the kinetic view[11-12]. Brunauer proposed BET multimolecular layer adsorption theory based on the single molecule adsorption theory[13]. Dubinin proposed the theory of micropore filling through experimental studies, namely the D-A adsorption equation[14]. Dubinin et al. proposed a D-R adsorption model through experimental studies[15]. H. Freundlich proposed the Freundlich isothermal adsorption equation based on the monolayer adsorption model[16].

(2) Study on influencing factors of coal adsorption. The factors affecting the coal adsorption characteristics mainly include macroscopic and microscopic aspects. Wang[17,18] et al. studied the coal adsorption capacity from the point of pore structure, moisture content and maceral components, and found that pore structure had the greatest influence on the adsorption capacity. Xu[19,20] found a positive correlation between coal metamorphism and coal pore characteristics through experiments, that is, the higher the metamorphism, the larger the adsorption capacity and pore capacity of coal. Jiang[21] studied the influence of coal seam water injection pressure on coal adsorption performance through experiments, and the results showed that coal adsorption capacity increased with the increase of water injection pressure. Deng[22,23] used ZRJ-1 coal spontaneous combustion tester to study the effect of temperature on oxygen adsorption by coal, and the results showed that the oxygen adsorption of coal decreased with the increase of temperature. Zhou[24] used ZRJ-1 briquette spontaneous combustion tendency tester to study the influence of pore development on static oxygen uptake, and the results showed that transition pores and micropores had a greater impact on oxygen uptake, while large and medium pores had a lesser impact on oxygen uptake. Jin[25] explored the mechanism of coal under different pressure and temperature conditions by using Monte Carlo method (GCMC), and the results showed that the adsorption capacity of coal was positively related with pressure and negatively connected with temperature.

(3) Thermodynamic study of coal adsorption. The adsorption heat refers to the thermal effect produced in the process of adsorption, that is, the heat change in the adsorption system due to the surface force of solid adsorbed substance during the adsorption process. Chaback J[26] believed that the temperature change in the coal adsorption process was caused by the change of adsorption heat. Lu[27] analyzed the adsorption thermodynamic characteristics of coal with different degrees of metamorphism by using the theory of adsorption thermodynamics. Ma[28] calculated the adsorption heat of Dafosi coal during the adsorption process by using the adsorption thermodynamics theory. Lin[29] used the adsorption potential energy theory to test the adsorption process of gas molecules such as CO and CO_2 by coal samples under different temperature conditions, and then carried out thermodynamic calculation. Gu[30] used various adsorption thermodynamic equations to calculate the adsorption parameters of different gases adsorbed by coal samples. Jiang[31] studied the relationship between adsorption heat and adsorption capacity through experiments and software simulation.

4. Conclusion

(1) Identificated coal adsorption research literatures in recent years shows ascendant trend, degree of coal adsorption research concern more and more high. In 2019, with the proposal of coal energy conservation and emission reduction policies, the number of research literatures on coal adsorption showed a rapid growth trend. National policy, practical demand and scientific research promote each other to a certain extent, promoting the rapid development of coal adsorption research.

(2) China has published the most literature on coal adsorption. China University of Mining and Technology is the institution that studies the most coal adsorption. Yuanping Cheng is the author with the largest number of publications on coal adsorption. Fuel and International Journal of Coal Geology are the journals with the highest number of articles and the highest impact factors respectively.

(3) According to the relevant literature reports and the Citespace analysis results, the current research focus in the coal adsorption field are the heat change in the adsorption process and the factors affecting coal adsorption. In the future, the research in this field can be further studied from the point of pore structure and the influence of multi-factor coupling on coal adsorption capacity.

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