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Bibliometric Analysis: The Surface Modification of Activated Carbon in Increasing the Adsorption of Organic and Inorganic Pollutants

Suliestyah[1*], Indah Permata Sari[2], Bambang Cholis Suudi[2]

Department of Mining, Universitas Trisakti Jakarta[1]
Department of Industrial Technology, Universitas Trisakti Jakrta[2]

Corresponding Author: 1*

ABSTRACT— Activated carbon adsorption has been widely used as an alternative environmental treatment to reduce metal ions, but it is less effective against heavy metals and other pollutants, including organic and inorganic compounds. Surface modification is required to increase the adsorption of activated carbon. To build up the information related to adsorption power of activated carbon modification, this study evaluated the theme relevant to adsorption of activated carbon modification using keywords "activated carbon" and "surface modification" as the data input. The database utilized for bibliometric analysis in this study was from Scopus with the help of VOSviewer software for network visualization of authorship, countries, citations, affiliations, and keywords. The analysis was carried out on February 3, 2022. The author limited the data by its year from 2013 to 2020 and the result was 262 documents. The results portrayed that the publication of activated carbon modification has been highly rocketing in the last eight years, specifically from 2019 to 2021. China is the leading country in activated carbon modification research, which results in the highest publications, most cited authors, and affiliations. Additionally, Elsevier is a publisher with the most top publications in producing activated carbon modification research articles. The keyword analysis showed that the studies related to activated carbon modification were mostly concentrated on characteristics of activated carbon, surface characteristics, adsorption, and environmental treatment. This bibliometric analysis study presented the relevant information on the surface modification of activated carbon to boost dangerous pollutant adsorption in the direction of environmental treatment.

KEYWORDS: activated carbon adsorption, environmental treatment, surface modification, bibliometric analysis

1. INTRODUCTION

Heavy metal is one of the most high-risk water pollutions for organism. Pollution in consequence of heavy metal is being the global issue that should be solved. The industries such as mining, metallurgy, and chemical industry utilize heavy metals particularly Copper, Nickel, Lead, and Cadmium [8]. Moreover, industrial activities such as mining activities produce acid mine drainage containing toxic heavy metal ions such as Fe, Mn, Cd, Co, Zn and Ni due to the interaction of acid mine drainage with various types of mineral ores [1], [17], [35]. These heavy metals will accumulate in the environment when discharged as waste that is released into the waters. High concentrations of heavy metals as a result of their solubility in water can cause problems for organism, both humans, animals, and plants. The metal content of Pb, Cu, Ni and Ag can incite health problems in the form of disease to the kidneys [26] Zn and Co metals cause respiratory disorders, while Al and Fe metals can cause liver disease.

Several methods have been applied to eliminate heavy metals from wastewater using different mechanisms, such as adsorption using activated carbon as an adsorbent. Activated carbon is a solid material with high carbon content, has a large pore volume, a reactive surface, and a large contact surface, so it is very effective as an adsorbent [4], [39]. Absorption can be carried out for diverse purposes, including absorbing unwanted dyes, removing pollutants contained in wastewater [39] such as factory waste [36], and waste from mining activities [37]. Furthermore, they absorb harmful gases in exhaust gases from fuel combustion. Activated carbon is widely used as an adsorbent in both gas and liquid phases because of its easy operation, abundant availability, simple regeneration process, and good adsorption capacity [34]. Activated carbon has been synthesized from various carbon sources such as biomass, which includes palm shells [45], tamarind seeds [28], coconut shells [22], bamboo waste Y. J. Zhang et al., 2014, coffee grounds Pagalan et al., 2019) and low-rank coals such as sub-bituminous [27] and lignite [20], [9].

2. Methods

Various modification techniques have been used to increase the adsorption capacity of activated carbon for heavy metal ions. Modifications can be in the form of physical modifications or chemical modifications. Kharrazi activated carbon modification from lignocellulosic waste through physical activation using thermal stress and obtained an increase in adsorption for Cr and Pb of 51.14 and 160.48%, respectively [18]. The same thing was done by Macas-Garca to increase the adsorption of Cu ions [24]. Kasnejad introducing nitrogen functional groups to the surface of activated carbon to remove Cu ions from wastewater using HNO3 [15] and Kazeem impregnating Al to activated carbon to increase the acidic and alkaline sites of the activated carbon surface [16] are two examples of chemical modifications. Queiroz activated carbon modification with nitric acid to increase the uptake of heavy metal ions [31]. Research on the surface modification of activated carbon with surfactants such as sodium dodecyl sulfate (SDS) and ethyl trimethyl ammonium bromide (CTAB) has been carried out by [2]. The positively charged metal ions can be increased by using surfactants, especially anionic surfactants, because the negative charge on the activated carbon surface increases with the addition of surfactants [13].

The Scopus database was searched for articles, and the results were divided into three phases (Figure 1): (PHASE 1). It was related to search criteria definition for identifying the notes in the Scopus database and notes perfection, which was taken from the data collecting phase. In Phase 2, the documents were exported to VOSviewer software for bibliometric analysis based on publication, author, country, affiliation, publisher, and citation (data visualization phase): and (PHASE 3) the data analysis for identifying the main theme discussed in the developed study related to activated carbon modification.

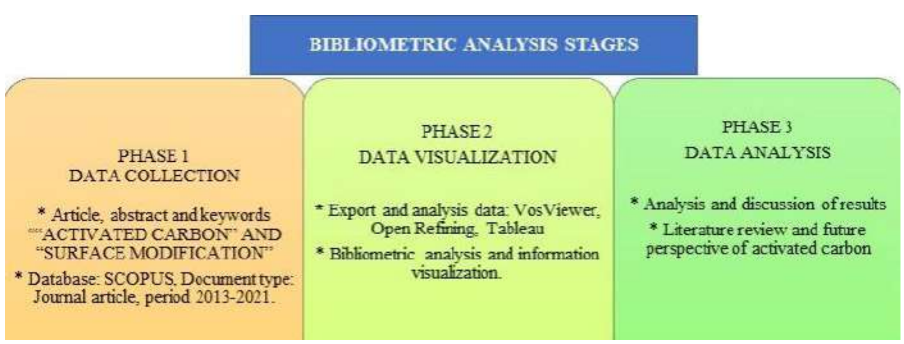

Figure 1 depicts the methodology phase, main steps, and analysis criteria used in this study.

Bibliometric analysis was referred to the research methodology used in library and information studies that used quantitative analysis and statistics methods to figure out the article distribution pattern for the given topic [11], delineate the article distribution pattern, ensure the authors' influence, affiliation, co-authors, or journal regionally [19], which aids in the identification of research trends, current issues, and new dynamics in multidisciplinary studies, country, and author [1]. Documents used in this study were taken from the Scous database platform, which is recognized as an ideal database for bibliometric analysis. The Scopus database covers information published in indexed journals from multidisciplinary studies. The search was conducted on February 3, 2022, with the inputted keywords being "Activated Carbon" and "Surface Modification". The data was restricted to the years 2013 to 2021 in order to obtain a more comprehensive result of publication data. In this study, the used literature was also limited to article journals, and after processing through Open Refine, the document results were 262. The final data was deployed for co-authorship and co-occurrence analysis. As a result, it may result in a network of author, country, and keyword.

The VOSviewer software (Version 1.6.17, Leiden University, Netherlands) was developed by Nees Jan Van Eck and Ludo Waltman, researchers from CWTS Leiden University. VOSviewer is a computer program provided freely which is helpful for creating and observing bibliometric networks. Unlike other computer programs commonly used for bibliometrics mapping, VOSviewer prioritizes graphic representation from bibliometric networks. The VOSviewer functionality is worthwhile to figure out the huge bibliometrics map with a simple interpretation [41]. In the process of VOSviewer, it is important to comprehend the terminology used by the software. The map which was created, visualized, and explored was using VOSviewer, followed by items. The map which was created, visualized, and explored was using VOSviewer, followed by items. "The items" are the profound objects. Those items might be publications, researchers, or others. A link is a connection or link between two items. The link examples are: bibliographic links among publications; authors' links among authors; co-authorship; and co-occurrence [42]. A link is a connection or link between two items. The link examples are: bibliographic links among publications; authors' links among authors; co-authorship; and co-occurrence. This bibliography is essential to identify the most cited article, influential author, impactful journal, powerful affiliations, and prominent countries in the study platform. This study also determined the citation total of a publication [6].

3. Results

As previously stated, the Scopus database found 262 publications on "surface activated carbon modification" for the period 2013 to 2021. The number of search publications showed an increasing trend in the mentioned period (Figure 2). The analysis reveals that between 2013 and 2019 there was a slow growth in the number of related activated carbon publications, and from 2020 that number increased quite rapidly, rocketing from 29 (2020) to 48 (2021). One of the explanations for this phenomenon is that between 2019 and 2021, a COVID-19 pandemic occurred that hit all countries in the world. As a consequence, the number of research projects since 2019 has stagnated. Moreover, there has been no increase in publication, with 48 publications for 2 years.

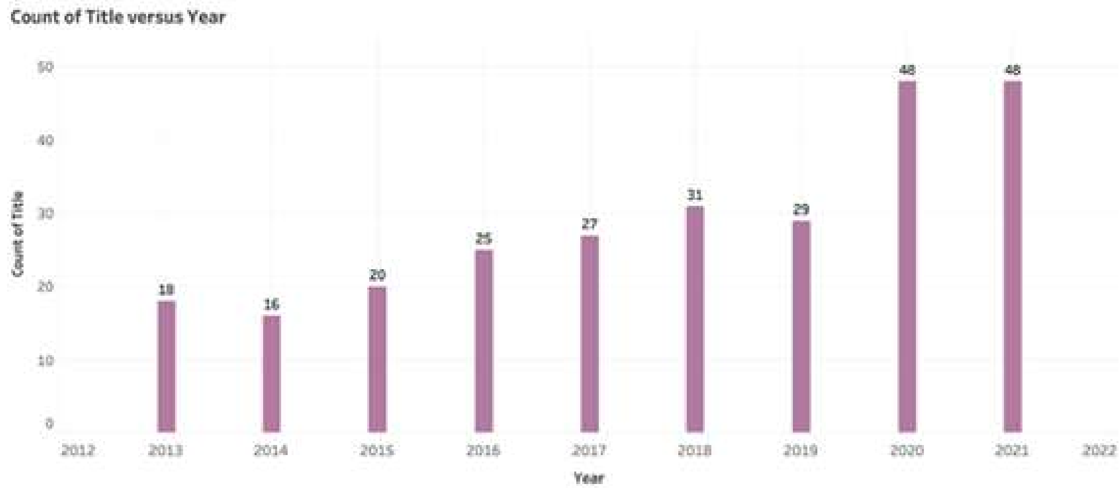

Figure 2. Quantitative distribution of publications of activated carbon surface modification studies, 2013 to 2021

According to the author analysis, by filtering 10 authors per document, of the 1022 authors, 909 met the threshold of one minimum document and one minimum citation, which consisted of seven clusters. The result was portrayed in figure 3.

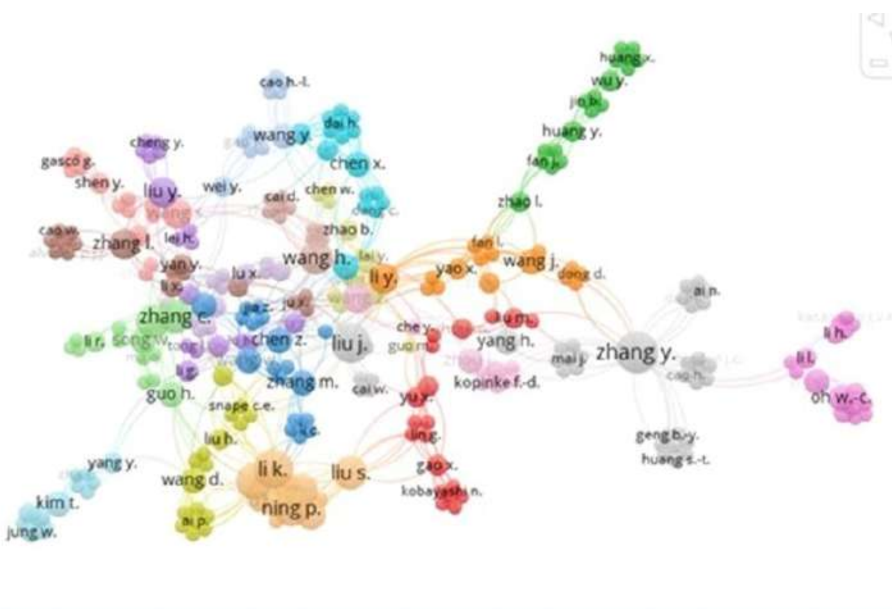

Figure 3. The distribution of the clusters of the authors of the article on the modification of activated carbon consisted of 7 clusters

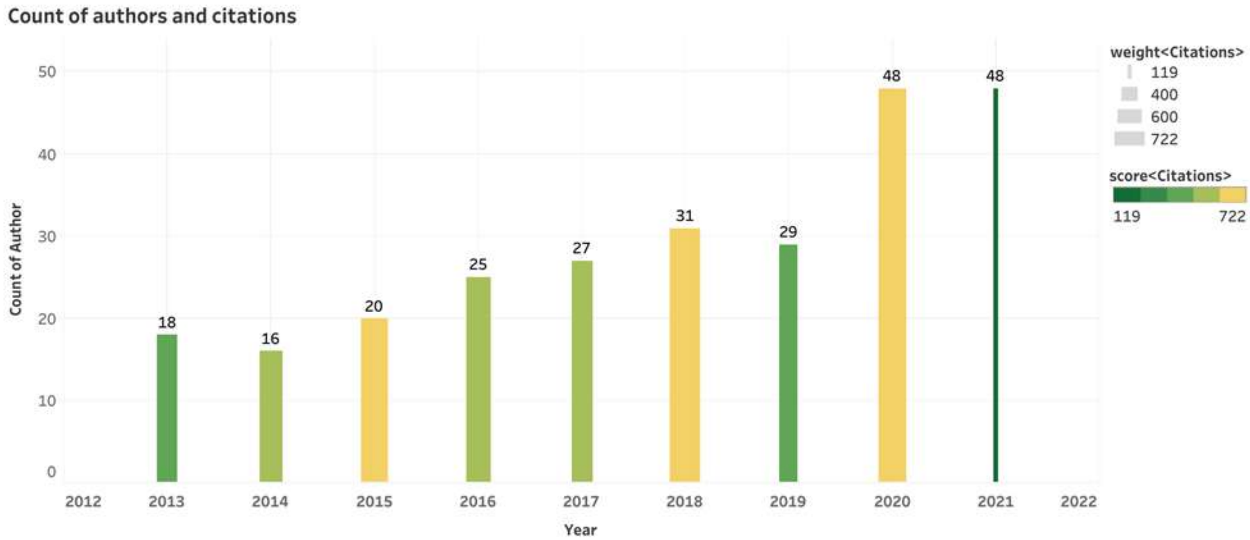

Figure 4. Citation total per year

Of the 262 authors, the top three authors were Li X, et al. with 148 citations; Ihsanullah, et al. with 146 citations; and Heidari A, with 139 citations. Figure 5 shows the top ten authors with the highest citations.

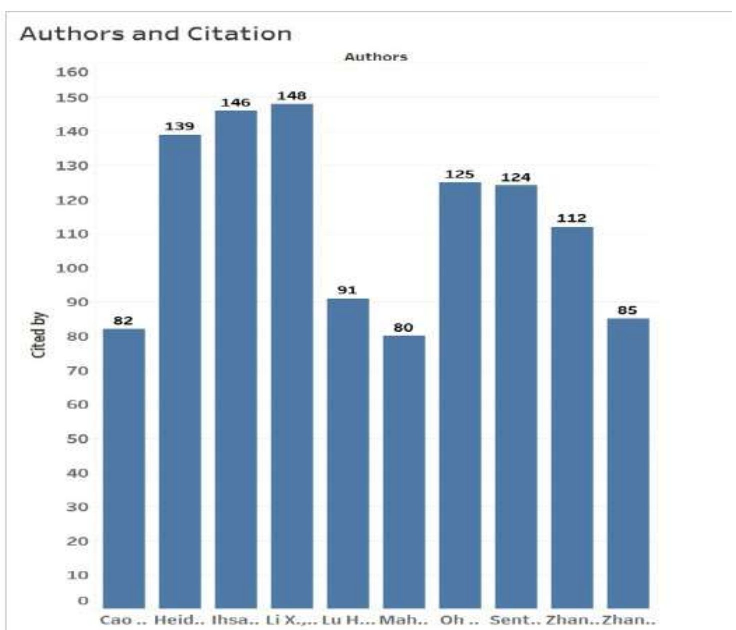

Figure 5. The top ten authors with the highest number of citations

From those top ten authors with the highest citations, it could be seen that the top title is in figure 6, and the discussed topic in each title has been explained through table 1.

Table 1. The article title with the highest citations

No	Author	Year	Title	Purpose and finding	Reference
1	Li X., Zhang L., Yang Z., Wang P., Yan Y., Ran J.	2020	Adsorption materials for volatile organic compounds (VOCs) and the key factors for VOCs adsorption process: A review	Review of the materials used for the adsorption of volatile organic compounds (VOCs) and the factors controlling the VOC adsorption process. Average specific surface area, pore volume and VOC adsorption capacity of adsorbent:	[21]

				metal organic framework (MOFs) > activated carbon (AC) > hyper crosslinked polymer resin (HPR) > zeolite. The mechanism of VOC adsorption in the adsorbent includes electrostatic attraction, interactions between polar VOCs and hydrophilic sites, interactions between non-polar VOCs and hydrophobic sites, and partitioning on non-carbonized sites. The adsorption capacity increases with increasing specific surface area, pore volume, and surface chemical functional groups and decreasing pore size. The micropore volume (size <0.7 nm) controlled the VOC adsorption.	
2	Ihsanullah, Al-Khaldi F.A., Abusharkh B., Khaled M., Atieh M.A., Nasser M.S., Laoui T., Saleh T.A., Agarwal S., Tyagi I., Gupta V.K.	2015	Adsorptive removal of cadmium(II) ions from liquid phase using acid modified carbon-based adsorbents	Comprehensive study of the adsorption characteristics of cadmium (II) on modified structures, such as carbon nanotubes (CNTs), carbon nanofibers (CNFs), activated carbon (AC), and fly ash (FA). Maximum adsorption capacity of The modified adsorbent was observed to be 2.02 mg/g, 1.98 mg/g, 1.22 mg/g and 1.58 mg/g, for CNT, AC, CNF and FA, as obtained from the Langmuir isotherm model. It was determined that the surface modification CNT, CNF, and AC increased their adsorption efficiency. This modified material is quite promising for use in water purification processes	[12]
3	Heidari A., Younesi H., Rashidi A., Ghoreyshi A.A.	2014	Evaluation of CO2 adsorption with eucalyptus wood based activated carbon modified by ammonia solution through heat treatment	Eucalyptus wood is used to produce activated carbon through chemical activation with H3PO4 as an adsorbent for CO2 adsorption. The results showed that the modification of activated carbon at a high temperature increased the BET surface area and micropore volume. The results showed that physical parameters such as surface area, lower pore diameter, and larger micropore volume of carbon samples showed an influence on the amount of CO2 adsorbed. The CO2 adsorption capacity achieved by the modified carbon was 3.22 mmol/g at 1 bar and 303 K, which is more than pure carbon (2.9 mmol/g). Thermodynamic parameters indicate that the adsorption process is spontaneous and exothermic, and the dominant mechanism for CO2 adsorption is physisorption.	[10]
4	Oh W.-D., Lua S.-K., Dong Z., Lim T.-T.	2015	Performance of magnetic activated carbon composite as peroxymonosulfate activator and regenerable adsorbent via sulfate radical-mediated oxidation processes	A magnetic activated carbon composite (CuFe2O4/AC, MACC) was prepared by the co-precipitation-calcination method. The performance of MACC was evaluated as a catalyst and an adsorbent which can be regenerated through the activation of peroxymonosulfate (PMS, Oxone®) for the removal of methylene blue (MB). The optimum CuFe2O4/AC w/w ratio is 1:1.5,	[30]

				giving excellent performance and can be reused for at least 3 cycles. The presence of common inorganic ions, namely Cl-and NO3-, did not have a significant effect on MB degradation, but humic acid decreased the MB degradation rate. As a regenerating adsorbent, a negligible difference in regeneration efficiency was observed when higher doses of Oxone® were used, but better efficiency was obtained at lower MACC loadings. The factors that inhibit the complete MACC regeneration are the irreversibility of MB adsorption and the modification of the AC surface by PMS, so that it is less favorable for subsequent MB adsorption. The regeneration rate increases linearly as the Oxone®: MACC ratio increases. MACC has the potential to function as a catalyst for PMS activation and regenerating adsorbents.	
5	Senthil Kumar P., Varjani S.J., Suganya S.	2018	Treatment of dye wastewater using an ultrasonic aided nanoparticle stacked activated carbon: Kinetic and isotherm modelling	This work describes the biosorption of bronze green dye from an aquatic system by nano-valence iron-coated activated carbon (NZVI-AC), which was prepared by a dual surface modification strategy. NZVI-AC showed efficient performance in dye biosorption properties. Experimental variables such as time, pH, dye concentration, temperature, and dose of biosorbent affect Langmuir's adsorption capacity of 187.3 mg/g. The current biosorption system is best described by pseudo-first-order kinetics.	[33]
6	Zhang C., Song W., Ma Q., Xie L., Zhang X., Guo H.	2016	Enhancement of CO2 Capture on Biomass-Based Carbon from Black Locust by KOH Activation and Ammonia Modification	A new biomass-based carbon material was successfully prepared from black grasshoppers by chemically activating KOH in combination with surface modification by heat treatment with ammonia solution to enhance CO2 adsorption. The results showed that the modified activated carbon had a high surface area of 2511 m2/g, a large micropore volume of 1.16 cm3/g, and a high nitrogen content of 7.21% by weight. High CO2 adsorption of 7.19 and 5.05 mmol/g at 0 and 25 °C was achieved for the AC-KOH-N sample due to its well-developed micropore structure and abundant basic nitrogen-containing functionality. The thermodynamic parameters showed that the physical adsorption and chemical adsorption mechanisms for CO2 adsorption were present in the AC-KOH-N sample. AC-KOH-N samples also showed good selectivity for CO2/N2 and fast adsorption kinetics, which were easily regenerated with superior cyclic stability after several cycles. These results indicate that the obtained biomass-based activated carbon is promising for CO2 capture.	[46]

7	Lu H.P., Li Z.A., Gascó G., Méndez A., Shen Y., Paz-Ferreiro J.	2018	Use of magnetic biochars for the immobilization of heavy metals in a multi-contaminated soil	Modified biochar, such as magnetic biochar, is analyzed to remove inorganic pollutants. Magnetic and conventional biochar were prepared from two raw materials (poultry waste and eucalyptus) at temperatures of 300 and 500 °C. Sequential extraction procedures have been carried out for heavy metal speciation and phytotoxicity tests using rice. Acid-soluble Cd in PLB-modified soil was 8 to 10% lower than in control polluted soil. This figure is 27 to 29% for acid-soluble Zn and 59 to 63% for acid-soluble Cu. In some cases, discrepancies were found between the heavy metal fractionation in samples treated with magnetic and conventional biochar. Plant biomass was not affected by most treatments, but increased by 32% in treatments containing magnetic poultry litter biochar. Our study shows that careful choice of raw materials is critical to the successful containment of heavy metals in multi-contaminated mining area soils. In the case of this study, the choice of the right raw material (in the case of this study, poultry litter vs. eucalyptus) is more decisive with respect to pollutant mobility than changing the pyrolysis temperature or modifying surface properties through magnetization. However, surface modification through magnetization can have a significant impact on crop yields and offer a comparative advantage in the management of some degraded landscapes.	[23]
8	Zhang X., Gu P., Li X., Zhang G.	2017	Efficient adsorption of radioactive iodide ion from simulated wastewater by nano Cu2O/Cu activated carbon modification	The Nano Cu2O/Cu modified activated carbon composite (nano Cu2O/Cu-C) was synthesized by a hydrothermal method to adsorb iodide ions (I) from radioactive waste. The composite showed excellent adsorption performance, which was due to the synergistic effect of nano Cu2O/Cu and activated carbon. Based on the Langmuir isotherm, the maximum adsorption capacity of I by nanoCu2O/Cu-C was 41.2 mg/g, which was significantly higher than that of pure nanoCu2O and activated carbon. Adsorption is only affected by pH and other interfering ions.	[47]
9	Cao H., Xing L., Wu G., Xie Y., Shi S., Zhang Y., Minakata D., Crittenden J.C.	2014	Promoting effect of nitration modification on activated carbon in the catalytic ozonation of oxalic acid	This study modifies commercial activated carbon (AC) by the nitration or amination methods and analyzes the effects of texture and chemical properties on the ability of AC samples to destroy oxalic acid (OA) using ozone. The level of OA degradation in the nitrated and amination AC samples increased by 38.5% and 9.6%, respectively. The adsorption capacity of AC samples did not increase after modification, but the rate of decomposition of ozone in solution increased. The surface area of AC decreased	[5]

				significantly after nitration due to the entry of micropores, and some of the larger pores were blocked by the modified functional groups. The pHpzc values and Boehm titration results showed that nitration increased AC acidity. X-ray photoelectron spectroscopy (XPS) and temperature programmed desorption (TPD) results confirmed that -NO2 and acid oxygenated groups were simultaneously grafted onto AC during nitration. Meanwhile, the -NO2 group is completely reduced to NH2 and the carboxylate group is partially reduced during amination. The base group (NH2 and possibly a pyron group) increases the catalytic activity of the aminated AC sample, and the increased activity of the nitrated AC material is mainly due to the acid-oxygenated surface groups.	
10	Mahurin S.M., Górka J., Nelson K.M., Mayes R.T., Dai S.	2014	Enhanced CO2/N2 selectivity in amidoxime-modified porous carbon	The aim of this study was to modify the hierarchical porous carbon framework by using amidoxime functional groups through grafting for selective capture and removal of carbon dioxide from the combustion stream. The measured ideal CO2/N2 selectivity values for amidoxime grafted carbon were significantly higher than for pure porous carbon, with an increase of 65%. The overall CO2 capacity decreased slightly for activated carbon from 4.97 mmol g-1 to 4.24 mmol g-1 after surface modification due to the reduction of the total surface area. The isosteric heat of adsorption increased after the incorporation of amidoxime, which showed an increase in the interaction of CO2 with the sorbent. The total capacity was reproducible and stable after several adsorption/desorption cycles without loss of capacity, indicating that modification with amidoxime groups is a potential method to increase carbon capture.	[25]

Figure 6 shows the semantic network of documents issued by countries. The filter used in visualization with VOSviewer is a maximum of 10 countries per document, with a minimum of 1 document and 1 citation per country. There are 52 countries that produce 343 articles. As seen in the distribution, the People's Republic of China is the country that publishes the most articles on activated carbon modification with the production of 91 documents (25.5%), followed by India with 32 documents (9.3%) and South Korea with 30 documents (8.7%). It appears that the three countries producing the highest number of articles on activated carbon modification are countries in the Asian region. However, China occupies the top position with a much larger percentage compared to India and South Korea. It is because, apart from China's having the largest population, it also has abundant reserves of raw materials for making activated carbon, such as coal and wood.

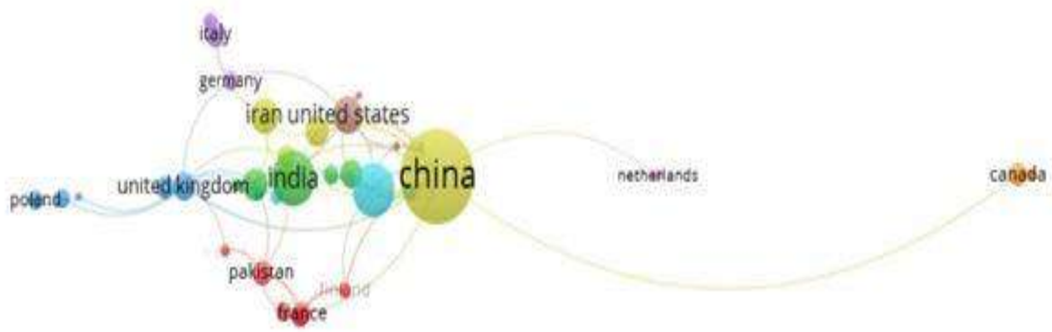

Figure 6. Article distribution based on countries

In terms of research centers involved in the study, with a maximum of 10 affiliated institutions per document, a minimum of one document and one citation per affiliated Institution, this study identified 520 institutions participating in publications on surface modification of activated carbon. The top ten institutions with the largest number of published documents on the topic of hierarchically structured activated carbon surface modification was explained in the Tree Map of Figure 6. Size and color represent separate numerical dimensions of the data. The Faculty of Environmental Science and Engineering, Kunming University of Science and Technology, China, is the affiliated institution with the most documents (3 documents). The top ten affiliate data is presented in Figure 7.

Figure 7. Top ten affiliations producing articles related to surface modification of activated carbon

Another crucial aspect to analyze is the number of journal citations to identify key areas of research involving activated carbon surface modification. The documents obtained in this study were published by 35 well-known publishers. For the top ten publishers who publish the most articles on the surface modification of activated carbon (Figure 7). In Figure 8, the publishers with the highest number of articles on activated carbon are Elsevier BV, followed by Elsevier Ltd.

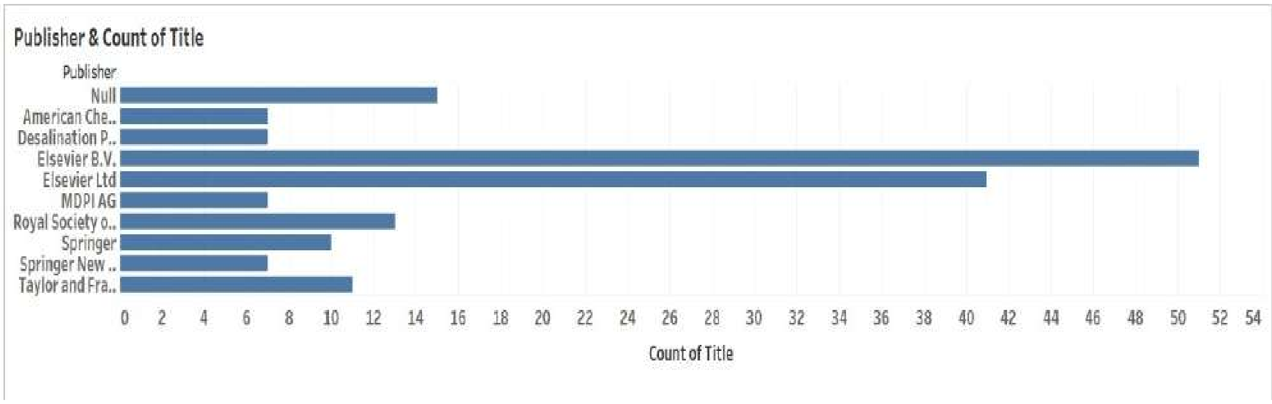

Figure 8. Top ten publisher with the highest number of articles in activated carbon surface modification

To verify the scope and main theme of the studies related to activated carbon surface modification, it is important to analyze deeply every document and extract its main keywords. This analysis is fundamental to ponder the trends of the prominent themes and identify the hotspot which is probably interesting as further research, development, and innovation. The keywords analysis linked with activated carbon surface modification consisted of 2.823 keywords. In contrast, after tightening the keywords, the author resulted 220 keywords divided into five clusters (figure 9).

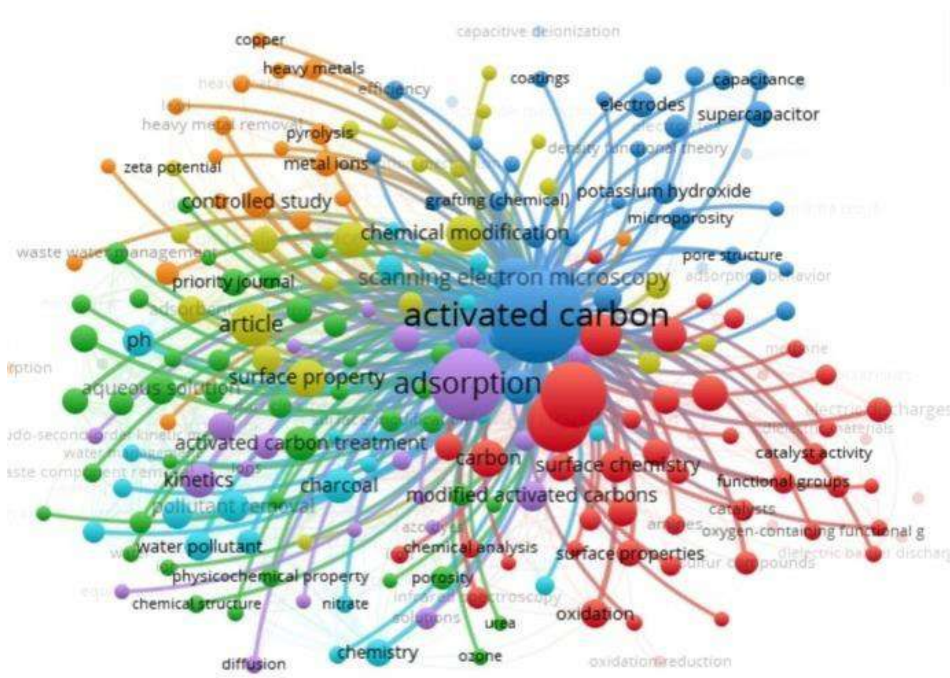

Figure 8. Network visualization of keywords based on total link strength

The keywords obtained were classified into five clusters. The main keywords that were highlighted the most throughout the network in this cluster were in cluster 1, which focused on "activated carbon," which is closely related to scanning electron microscopy, chemical modification, pore structure, micro porosity, adsorption behavior, and specific capacitance. In cluster 2, the term that stands out is "adsorption". The main words in this cluster are related to adsorption mechanisms, such as activated carbon treatment, isotherm adsorption, and adsorbent. In cluster 3, the highlighted term is "surface modification", which is closely related to the keywords surface treatment, activated carbon modification, surface properties, functional group, and catalytic activity. In cluster 4, terms related to environmental problems appear more often, such as activated carbon treatment, water pollution, and waste water management. Finally, in cluster 5, the most prominent term is "chemical modification," followed by surface property and article.

According to keywords that often appear in the five clusters, several studies elucidate a close relationship between keywords. Scanning electron microscopy is often used to see changes in the surface morphology of activated carbon and activated carbon that has undergone modifications on its surface. This surface morphology can show the nature of its porosity and pore structure. Is the activated carbon included in the micropore, mesopore, or macropore? The nature and structure of these pores will affect the adsorption behavior as well as the adsorption capacity [29], [36]. Activated carbon adsorption is an activated carbon treatment method to absorb dyes, metal ions, and also anions contained in liquid waste. In addition, activated carbon adsorption can also be used in gas absorption, both to absorb toxic gases and to store hydrogen gas. Isothermal adsorption studies using the Langmuir or Freundlich models are frequently used to determine the adsorption capacity of activated carbon [14], [40], [44]. For high valence metals, activated carbon can often not be absorbed optimally. Hence, it is necessary to modify the surface of the activated carbon to increase its absorption. The purpose of the modification to the surface is to change the nature and structure of the surface of the activated carbon so that it has more active groups. Surface treatment in the activated carbon modification process is strongly influenced by surface properties, such as functional groups and catalytic activity [3], [38]. Activated carbon treatment is an alternative that can be used in environmental treatment, such as water treatment and waste water management [7], [32], [43].

4. Discussion

This work has shown that surface modification of activated carbon has been widely carried out to increase the adsorption capacity of activated carbon, and the number of documents published is increasing every year. In contrast to the bibliometric analysis conducted by [19], which emphasizes the modification of adsorbents with ionic liquids to absorb organic pollutants, the bibliometric analysis conducted by Salam, 2019 which emphasizes the application of modified activated carbon to improve water quality, the bibliometric analysis conducted by [2], which emphasizes the adsorption of arsenic metal in drinking water, the bibliometric analysis in this research has a wider scope in terms of the application of modified activated carbon, including the adsorption of volatile organic compounds [3], adsorption of Cd metal ions [12], CO2 gas adsorption [10], [46] adsorption of color and wastewater treatment [33] heavy metal adsorption [4], and radioactive iodide ion adsorption [5]

This bibliometric analysis provides benefits in the form of a reference for researchers who will conduct research on the surface modification of activated carbon as well as its application as an adsorbent. This is important because surface modification of activated carbon can increase adsorption capacity by increasing specific surface area, pore volume, and surface chemical functional groups and decreasing pore size [3], [47], [25]. In addition, it also provides a reference on the thermodynamic aspects of the surface modification of activated carbon, which shows whether the adsorption process is spontaneous and exothermic and how the dominant mechanism is physisorption or chemisorption [10].

Future perspectives for the problem of surface modification of activated carbon will continue to develop. Therefore, therefore an up-to-date bibliometric analysis is needed with an analysis time span of several years to come.

5. Conclusions

This study reports a bibliometric analysis of 262 publications extracted from the Scopus database, which focuses on activated carbon modification. This study presented information related to publication sources, articles, authors, affiliated institutions, publishers, countries, and the most cited themes on modified activated carbon. The results illustrated that in the last 8 years, publications on the surface modification of activated carbon increased significantly, especially between 2019 and 2021. The analysis related to the authors showed that the authors with the highest number of citations were Li X et al. with 148 citations, Ihsanullah et al. with 146 citations, and Heidari A with 139 citations. Meanwhile, the analysis of affiliated institutions shows that the Faculty of Environmental Science and Engineering, Kunming University of Science and Technology, China, is the affiliated institution with the most documents. Elsevier BV and Elsevier Ltd are the publishers who publish the most articles on activated carbon. The countries that publish the most articles on activated carbon modification include the People's Republic of China, India, and South Korea, with the percentages of publications being 25.5%, 9.3%, and 8.7%, respectively. Studies on modified activated carbon mostly focus on the characterization of activated carbon, surface properties, adsorption, and environmental treatment based on the results of keyword analysis. The bibliometric analysis in this study provides relevant information about the surface modification of activated carbon to increase the absorption of harmful metals in environmental treatment.

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Bibliometric Analysis: The Surface Modification of Activated Carbon in Increasing the Adsorption of Organic and Inorganic Pollutants

Suliestyah[1*], Indah Permata Sari[2], Bambang Cholis Suudi[2]

Department of Mining, Universitas Trisakti Jakarta[1]
Department of Industrial Technology, Universitas Trisakti Jakrta[2]

Corresponding Author: 1*

ABSTRACT— Activated carbon adsorption has been widely used as an alternative environmental treatment to reduce metal ions, but it is less effective against heavy metals and other pollutants, including organic and inorganic compounds. Surface modification is required to increase the adsorption of activated carbon. To build up the information related to adsorption power of activated carbon modification, this study evaluated the theme relevant to adsorption of activated carbon modification using keywords "activated carbon" and "surface modification" as the data input. The database utilized for bibliometric analysis in this study was from Scopus with the help of VOSviewer software for network visualization of authorship, countries, citations, affiliations, and keywords. The analysis was carried out on February 3, 2022. The author limited the data by its year from 2013 to 2020 and the result was 262 documents. The results portrayed that the publication of activated carbon modification has been highly rocketing in the last eight years, specifically from 2019 to 2021. China is the leading country in activated carbon modification research, which results in the highest publications, most cited authors, and affiliations. Additionally, Elsevier is a publisher with the most top publications in producing activated carbon modification research articles. The keyword analysis showed that the studies related to activated carbon modification were mostly concentrated on characteristics of activated carbon, surface characteristics, adsorption, and environmental treatment. This bibliometric analysis study presented the relevant information on the surface modification of activated carbon to boost dangerous pollutant adsorption in the direction of environmental treatment.

KEYWORDS: activated carbon adsorption, environmental treatment, surface modification, bibliometric analysis

1. INTRODUCTION

Heavy metal is one of the most high-risk water pollutions for organism. Pollution in consequence of heavy metal is being the global issue that should be solved. The industries such as mining, metallurgy, and chemical industry utilize heavy metals particularly Copper, Nickel, Lead, and Cadmium [8]. Moreover, industrial activities such as mining activities produce acid mine drainage containing toxic heavy metal ions such as Fe, Mn, Cd, Co, Zn and Ni due to the interaction of acid mine drainage with various types of mineral ores [1], [17], [35]. These heavy metals will accumulate in the environment when discharged as waste that is released into the waters. High concentrations of heavy metals as a result of their solubility in water can cause problems for organism, both humans, animals, and plants. The metal content of Pb, Cu, Ni and Ag can incite health problems in the form of disease to the kidneys [26] Zn and Co metals cause respiratory disorders, while Al and Fe metals can cause liver disease.

Several methods have been applied to eliminate heavy metals from wastewater using different mechanisms, such as adsorption using activated carbon as an adsorbent. Activated carbon is a solid material with high carbon content, has a large pore volume, a reactive surface, and a large contact surface, so it is very effective as an adsorbent [4], [39]. Absorption can be carried out for diverse purposes, including absorbing unwanted dyes, removing pollutants contained in wastewater [39] such as factory waste [36], and waste from mining activities [37]. Furthermore, they absorb harmful gases in exhaust gases from fuel combustion. Activated carbon is widely used as an adsorbent in both gas and liquid phases because of its easy operation, abundant availability, simple regeneration process, and good adsorption capacity [34]. Activated carbon has been synthesized from various carbon sources such as biomass, which includes palm shells [45], tamarind seeds [28], coconut shells [22], bamboo waste Y. J. Zhang et al., 2014, coffee grounds Pagalan et al., 2019) and low-rank coals such as sub-bituminous [27] and lignite [20], [9].

Methods

Various modification techniques have been used to increase the adsorption capacity of activated carbon for heavy metal ions. Modifications can be in the form of physical modifications or chemical modifications. Kharrazi activated carbon modification from lignocellulosic waste through physical activation using thermal stress and obtained an increase in adsorption for Cr and Pb of 51.14 and 160.48%, respectively [18]. The same thing was done by Macas-Garca to increase the adsorption of Cu ions [24]. Kasnejad introducing nitrogen functional groups to the surface of activated carbon to remove Cu ions from wastewater using HNO_3 [15] and Kazeem impregnating Al to activated carbon to increase the acidic and alkaline sites of the activated carbon surface [16] are two examples of chemical modifications. Quiroz activated carbon modification with nitric acid to increase the uptake of heavy metal ions [31]. Research on the surface modification of activated carbon with surfactants such as sodium dodecyl sulfate (SDS) and ethyl trimethyl ammonium bromide (CTAB) has been carried out by [2]. The positively charged metal ions can be increased by using surfactants, especially anionic surfactants, because the negative charge on the activated carbon surface increases with the addition of surfactants [13].

The Scopus database was searched for articles, and the results were divided into three phases (Figure 1): (PHASE 1). It was related to search criteria definition for identifying the notes in the Scopus database and notes perfection, which was taken from the data collecting phase. In Phase 2, the documents were exported to VOSviewer software for bibliometric analysis based on publication, author, country, affiliation, publisher, and citation (data visualization phase): and (PHASE 3) the data analysis for identifying the main theme discussed in the developed study related to activated carbon modification.

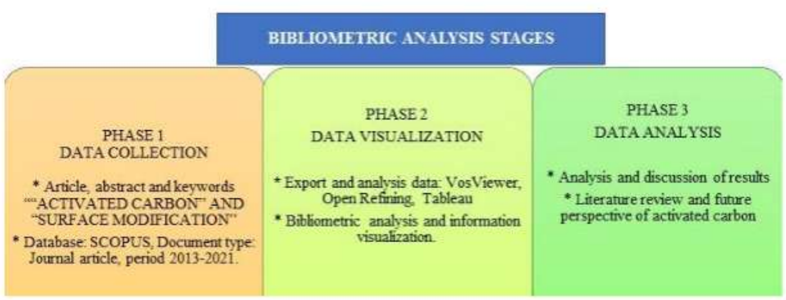

Figure 1 depicts the methodology phase, main steps, and analysis criteria used in this study.

Bibliometric analysis was referred to the research methodology used in library and information studies that used quantitative analysis and statistics methods to figure out the article distribution pattern for the given topic [11], delineate the article distribution pattern, ensure the authors' influence, affiliation, co-authors, or journal regionally [19], which aids in the identification of research trends, current issues, and new dynamics in

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multidisciplinary studies, country, and author [1]. Documents used in this study were taken from the Scous database platform, which is recognized as an ideal database for bibliometric analysis. The Scopus database covers information published in indexed journals from multidisciplinary studies. The search was conducted on February 3, 2022, with the inputted keywords being "Activated Carbon" and "Surface Modification". The data was restricted to the years 2013 to 2021 in order to obtain a more comprehensive result of publication data. In this study, the used literature was also limited to article journals, and after processing through Open Refine, the document results were 262. The final data was deployed for co-authorship and co-occurrence analysis. As a result, it may result in a network of author, country, and keyword.

The VOSviewer software (Version 1.6.17, Leiden University, Netherlands) was developed by Nees Jan Van Eck and Ludo Waltman, researchers from CWTS Leiden University. VOSviewer is a computer program provided freely which is helpful for creating and observing bibliometric networks. Unlike other computer programs commonly used for bibliometrics mapping, VOSviewer prioritizes graphic representation from bibliometric networks. The VOSviewer functionality is worthwhile to figure out the huge bibliometrics map with a simple interpretation [41]. In the process of VOSviewer, it is important to comprehend the terminology used by the software. The map which was created, visualized, and explored was using VOSviewer, followed by items. The map which was created, visualized, and explored was using VOSviewer, followed by items. "The items" are the profound objects. Those items might be publications, researchers, or others. A link is a connection or link between two items. The link examples are: bibliographic links among publications; authors' links among authors; co-authorship; and co-occurrence [42]. A link is a connection or link between two items. The link examples are: bibliographic links among publications; authors' links among authors; co-authorship; and co-occurrence. This bibliography is essential to identify the most cited article, influential author, impactful journal, powerful affiliations, and prominent countries in the study platform. This study also determined the citation total of a publication [6].

3. Results

As previously stated, the Scopus database found 262 publications on "surface activated carbon modification" for the period 2013 to 2021. The number of search publications showed an increasing trend in the mentioned period (Figure 2). The analysis reveals that between 2013 and 2019 there was a slow growth in the number of related activated carbon publications, and from 2020 that number increased quite rapidly, rocketing from 29 (2020) to 48 (2021). One of the explanations for this phenomenon is that between 2019 and 2021, a COVID-19 pandemic occurred that hit all countries in the world. As a consequence, the number of research projects since 2019 has stagnated. Moreover, there has been no increase in publication, with 48 publications for 2 years.

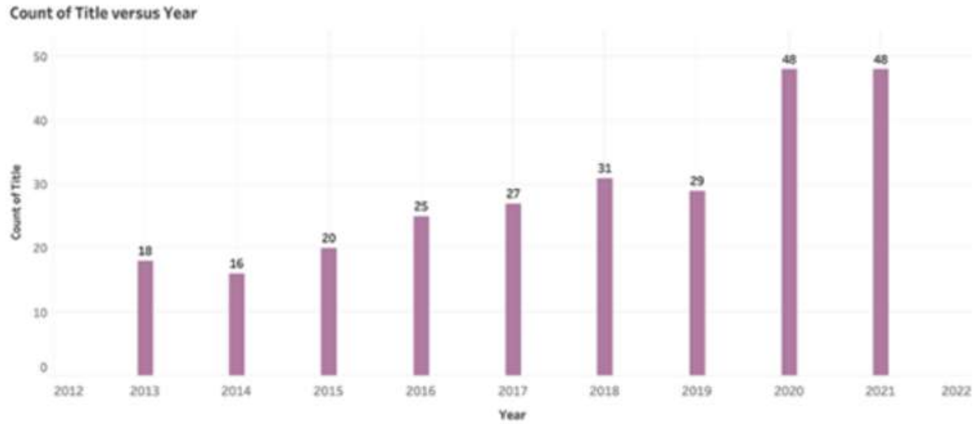

Figure 2. Quantitative distribution of publications of activated carbon surface modification studies, 2013 to 2021

According to the author analysis, by filtering 10 authors per document, of the 1022 authors, 909 met the threshold of one minimum document and one minimum citation, which consisted of seven clusters. The result was portrayed in figure 3.

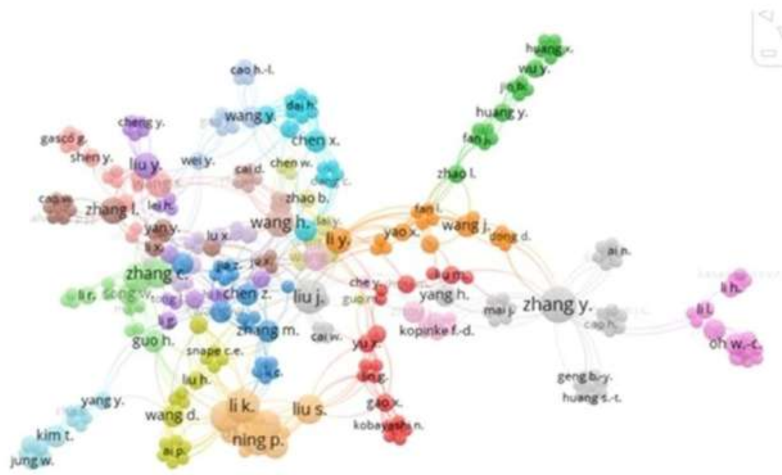

Figure 3. The distribution of the clusters of the authors of the article on the modification of activated carbon consisted of 7 clusters

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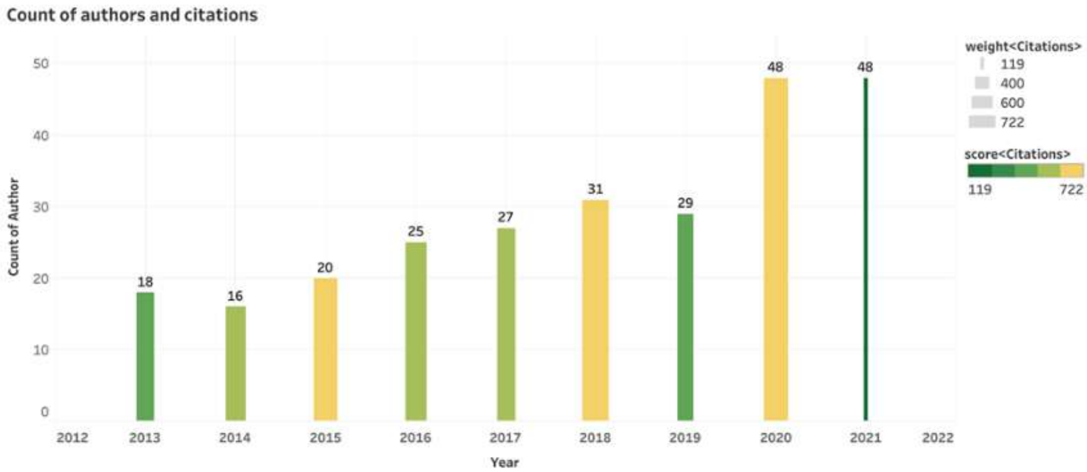

Figure 4. Citation total per year

Of the 262 authors, the top three authors were Li X, et al. with 148 citations; Ihsanullah, et al. with 146 citations; and Heidari A, with 139 citations. Figure 5 shows the top ten authors with the highest citations.

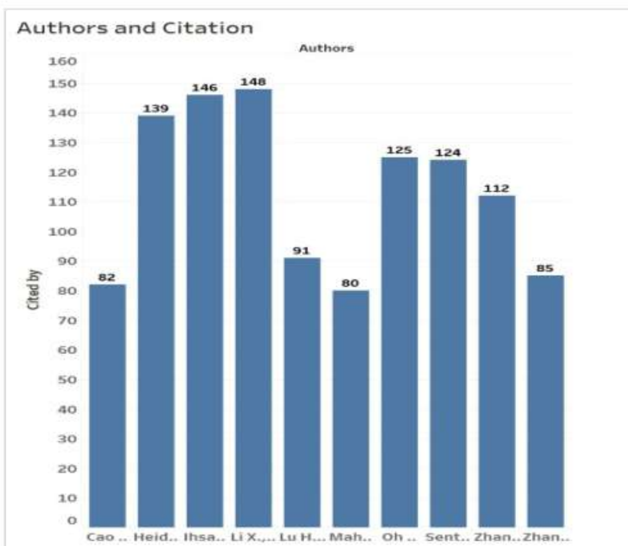

Figure 5. The top ten authors with the highest number of citations

From those top ten authors with the highest citations, it could be seen that the top title is in figure 6, and the discussed topic in each title has been explained through table 1.

Table 1. The article title with the highest citations

No	Author	Year	Title	Purpose and finding	Reference
1	Li X., Zhang L., Yang Z., Wang P., Yan Y., Ran J.	2020	Adsorption materials for volatile organic compounds (VOCs) and the key factors for VOCs adsorption process: A review	Review of the materials used for the adsorption of volatile organic compounds (VOCs) and the factors controlling the VOC adsorption process. Average specific surface area, pore volume and VOC adsorption capacity of adsorbent:	[21]

				metal organic framework (MOFs) > activated carbon (AC) > hyper crosslinked polymer resin (HPR) > zeolite. The mechanism of VOC adsorption in the adsorbent includes electrostatic attraction, interactions between polar VOCs and hydrophilic sites, interactions between non-polar VOCs and hydrophobic sites, and partitioning on non-carbonized sites. The adsorption capacity increases with increasing specific surface area, pore volume, and surface chemical functional groups and decreasing pore size. The micropore volume (size <0.7 nm) controlled the VOC adsorption.	
2	Ihsanullah, Al-Khaldi F.A., Abusharkh B., Khaled M., Atieh M.A., Nasser M.S., Laoui T., Saleh T.A., Agarwal S., Tyagi I., Gupta V.K.	2015	Adsorptive removal of cadmium(II) ions from liquid phase using acid modified carbon-based adsorbents	Comprehensive study of the adsorption characteristics of cadmium (II) on modified structures, such as carbon nanotubes (CNTs), carbon nanofibers (CNFs), activated carbon (AC), and fly ash (FA). Maximum adsorption capacity of The modified adsorbent was observed to be 2.02 mg/g, 1.98 mg/g, 1.22 mg/g and 1.58 mg/g, for CNT, AC, CNF and FA, as obtained from the Langmuir isotherm model. It was determined that the surface modification CNT, CNF, and AC increased their adsorption efficiency. This modified material is quite promising for use in water purification processes	[12]
3	Heidari A., Younesi H., Rashidi A., Ghoreyshi A.A.	2014	Evaluation of CO2 adsorption with eucalyptus wood based activated carbon modified by ammonia solution through heat treatment	Eucalyptus wood is used to produce activated carbon through chemical activation with H_3PO_4 as an adsorbent for CO_2 adsorption. The results showed that the modification of activated carbon at a high temperature increased the BET surface area and micropore volume. The results showed that physical parameters such as surface area, lower pore diameter, and larger micropore volume of carbon samples showed an influence on the amount of CO_2 adsorbed. The CO_2 adsorption capacity achieved by the modified carbon was 3.22 mmol/g at 1 bar and 303 K, which is more than pure carbon (2.9 mmol/g). Thermodynamic parameters indicate that the adsorption process is spontaneous and exothermic, and the dominant mechanism for CO_2 adsorption is physisorption.	[10]
4	Oh W.-D., Lua S.-K., Dong Z., Lim T.-T.	2015	Performance of magnetic activated carbon composite as peroxymonosulfate activator and regenerable adsorbent via sulfate radical-mediated oxidation processes	A magnetic activated carbon composite ($CuFe_2O_4$/AC, MACC) was prepared by the co-precipitation-calcination method. The performance of MACC was evaluated as a catalyst and an adsorbent which can be regenerated through the activation of peroxymonosulfate (PMS, Oxone®) for the removal of methylene blue (MB). The optimum $CuFe_2O_4$/AC w/w ratio is 1:1.5,	[30]

				giving excellent performance and can be reused for at least 3 cycles. The presence of common inorganic ions, namely Cl-and NO3-, did not have a significant effect on MB degradation, but humic acid decreased the MB degradation rate. As a regenerating adsorbent, a negligible difference in regeneration efficiency was observed when higher doses of Oxone® were used, but better efficiency was obtained at lower MACC loadings. The factors that inhibit the complete MACC regeneration are the irreversibility of MB adsorption and the modification of the AC surface by PMS, so that it is less favorable for subsequent MB adsorption. The regeneration rate increases linearly as the Oxone®: MACC ratio increases. MACC has the potential to function as a catalyst for PMS activation and regenerating adsorbents	
5	Senthil Kumar P., Varjani S.J., Suganya S.	2018	Treatment of dye wastewater using an ultrasonic aided nanoparticle stacked activated carbon: Kinetic and isotherm modelling	This work describes the biosorption of bronze green dye from an aquatic system by nano-valence iron-coated activated carbon (NZVI-AC), which was prepared by a dual surface modification strategy. NZVI-AC showed efficient performance in dye biosorption properties. Experimental variables such as time, pH, dye concentration, temperature, and dose of biosorbent affect Langmuir's adsorption capacity of 187.3 mg/g. The current biosorption system is best described by pseudo-first-order kinetics.	[33]
6	Zhang C., Song W., Ma Q., Xie L., Zhang X., Guo H.	2016	Enhancement of CO2 Capture on Biomass-Based Carbon from Black Locust by KOH Activation and Ammonia Modification	A new biomass-based carbon material was successfully prepared from black grasshoppers by chemically activating KOH in combination with surface modification by heat treatment with ammonia solution to enhance CO2 adsorption. The results showed that the modified activated carbon had a high surface area of 2511 m2/g, a large micropore volume of 1.16 cm3/g, and a high nitrogen content of 7.21% by weight. High CO2 adsorption of 7.19 and 5.05 mmol/g at 0 and 25 °C was achieved for the AC-KOH-N sample due to its well-developed micropore structure and abundant basic nitrogen-containing functionality. The thermodynamic parameters showed that the physical adsorption and chemical adsorption mechanisms for CO2 adsorption were present in the AC-KOH-N sample. AC-KOH-N samples also showed good selectivity for CO2/N2 and fast adsorption kinetics, which were easily regenerated with superior cyclic stability after several cycles. These results indicate that the obtained biomass-based activated carbon is promising for CO2 capture.	[46]

7	Lu H.P., Li Z.A., Gascó G., Méndez A., Shen Y., Paz-Ferreiro J.	2018	Use of magnetic biochars for the immobilization of heavy metals in a multi-contaminated soil	Modified biochar, such as magnetic biochar, is analyzed to remove inorganic pollutants. Magnetic and conventional biochar were prepared from two raw materials (poultry waste and eucalyptus) at temperatures of 300 and 500 °C. Sequential extraction procedures have been carried out for heavy metal speciation and phytotoxicity tests using rice. Acid-soluble Cd in PLB-modified soil was 8 to 10% lower than in control polluted soil. This figure is 27 to 29% for acid-soluble Zn and 59 to 63% for acid-soluble Cu. In some cases, discrepancies were found between the heavy metal fractionation in samples treated with magnetic and conventional biochar. Plant biomass was not affected by most treatments, but increased by 32% in treatments containing magnetic poultry litter biochar. Our study shows that careful choice of raw materials is critical to the successful containment of heavy metals in multi-contaminated mining area soils. In the case of this study, the choice of the right raw material (in the case of this study, poultry litter vs. eucalyptus) is more decisive with respect to pollutant mobility than changing the pyrolysis temperature or modifying surface properties through magnetization. However, surface modification through magnetization can have a significant impact on crop yields and offer a comparative advantage in the management of some degraded landscapes.	[23]
8	Zhang X., Gu P., Li X., Zhang G.	2017	Efficient adsorption of radioactive iodide ion from simulated wastewater by nano Cu2O/Cu activated carbon modification	The Nano Cu2O/Cu modified activated carbon composite (nano Cu2O/Cu-C) was synthesized by a hydrothermal method to adsorb iodide ions (I) from radioactive waste. The composite showed excellent adsorption performance, which was due to the synergistic effect of nano Cu2O/Cu and activated carbon. Based on the Langmuir isotherm, the maximum adsorption capacity of I by nanoCu2O/Cu-C was 41.2 mg/g, which was significantly higher than that of pure nanoCu2O and activated carbon. Adsorption is only affected by pH and other interfering ions.	[47]
9	Cao H., Xing L., Wu G., Xie Y., Shi S., Zhang Y., Minakata D., Crittenden J.C.	2014	Promoting effect of nitration modification on activated carbon in the catalytic ozonation of oxalic acid	This study modifies commercial activated carbon (AC) by the nitration or amination methods and analyzes the effects of texture and chemical properties on the ability of AC samples to destroy oxalic acid (OA) using ozone. The level of OA degradation in the nitrated and amination AC samples increased by 38.5% and 9.6%, respectively. The adsorption capacity of AC samples did not increase after modification, but the rate of decomposition of ozone in solution increased. The surface area of AC decreased	[5]

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				significantly after nitration due to the entry of micropores, and some of the larger pores were blocked by the modified functional groups. The pHpzc values and Boehm titration results showed that nitration increased AC acidity. X-ray photoelectron spectroscopy (XPS) and temperature programmed desorption (TPD) results confirmed that -NO2 and acid oxygenated groups were simultaneously grafted onto AC during nitration. Meanwhile, the -NO2 group is completely reduced to NH2 and the carboxylate group is partially reduced during amination. The base group (NH2 and possibly a pyron group) increases the catalytic activity of the aminated AC sample, and the increased activity of the nitrated AC material is mainly due to the acid-oxygenated surface groups.	
10	Mahurin S.M., Górka J., Nelson K.M., Mayes R.T., Dai S.	2014	Enhanced CO2/N2 selectivity in amidoxime-modified porous carbon	The aim of this study was to modify the hierarchical porous carbon framework by using amidoxime functional groups through grafting for selective capture and removal of carbon dioxide from the combustion stream. The measured ideal CO2/N2 selectivity values for amidoxime grafted carbon were significantly higher than for pure porous carbon, with an increase of 65%. The overall CO2 capacity decreased slightly for activated carbon from 4.97 mmol g-1 to 4.24 mmol g-1 after surface modification due to the reduction of the total surface area. The isosteric heat of adsorption increased after the incorporation of amidoxime, which showed an increase in the interaction of CO2 with the sorbent. The total capacity was reproducible and stable after several adsorption/desorption cycles without loss of capacity, indicating that modification with amidoxime groups is a potential method to increase carbon capture.	[25]

Figure 6 shows the semantic network of documents issued by countries. The filter used in visualization with VOSviewer is a maximum of 10 countries per document, with a minimum of 1 document and 1 citation per country. There are 52 countries that produce 343 articles. As seen in the distribution, the People's Republic of China is the country that publishes the most articles on activated carbon modification with the production of 91 documents (25.5%), followed by India with 32 documents (9.3%) and South Korea with 30 documents (8.7%). It appears that the three countries producing the highest number of articles on activated carbon modification are countries in the Asian region. However, China occupies the top position with a much larger percentage compared to India and South Korea. It is because, apart from China's having the largest population, it also has abundant reserves of raw materials for making activated carbon, such as coal and wood.

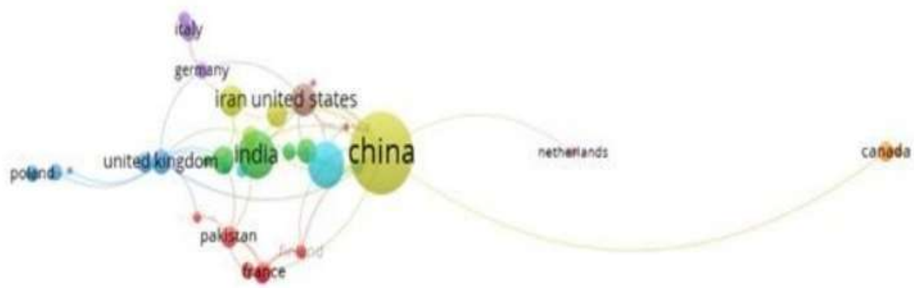

Figure 6. Article distribution based on countries

In terms of research centers involved in the study, with a maximum of 10 affiliated institutions per document, a minimum of one document and one citation per affiliated Institution, this study identified 520 institutions participating in publications on surface modification of activated carbon. The top ten institutions with the largest number of published documents on the topic of hierarchically structured activated carbon surface modification was explained in the Tree Map of Figure 6. Size and color represent separate numerical dimensions of the data. The Faculty of Environmental Science and Engineering, Kunming University of Science and Technology, China, is the affiliated institution with the most documents (3 documents). The top ten affiliate data is presented in Figure 7.

Figure 7. Top ten affiliations producing articles related to surface modification of activated carbon

Another crucial aspect to analyze is the number of journal citations to identify key areas of research involving activated carbon surface modification. The documents obtained in this study were published by 35 well-known publishers. For the top ten publishers who publish the most articles on the surface modification of activated carbon (Figure 7). In Figure 8, the publishers with the highest number of articles on activated carbon are Elsevier BV, followed by Elsevier Ltd.

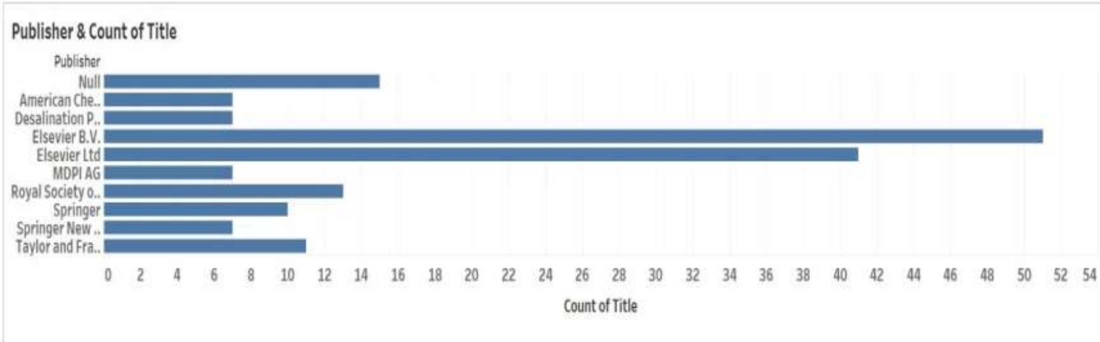

Figure 8. Top ten publisher with the highest number of articles in activated carbon surface modification

To verify the scope and main theme of the studies related to activated carbon surface modification, it is important to analyze deeply every document and extract its main keywords. This analysis is fundamental to ponder the trends of the prominent themes and identify the hotspot which is probably interesting as further research, development, and innovation. The keywords analysis linked with activated carbon surface modification consisted of 2.823 keywords. In contrast, after tightening the keywords, the author resulted 220 keywords divided into five clusters (figure 9).

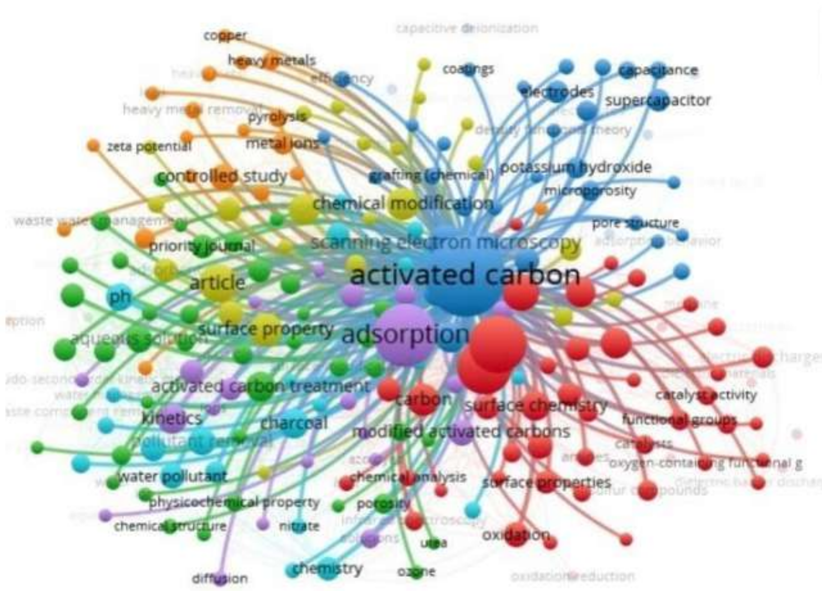

Figure 8. Network visualization of keywords based on total link strength

The keywords obtained were classified into five clusters. The main keywords that were highlighted the most throughout the network in this cluster were in cluster 1, which focused on "activated carbon," which is closely related to scanning electron microscopy, chemical modification, pore structure, micro porosity, adsorption behavior, and specific capacitance. In cluster 2, the term that stands out is "adsorption". The main words in this cluster are related to adsorption mechanisms, such as activated carbon treatment, isotherm adsorption, and adsorbent. In cluster 3, the highlighted term is "surface modification", which is closely related to the keywords surface treatment, activated carbon modification, surface properties, functional group, and catalytic activity. In cluster 4, terms related to environmental problems appear more often, such as activated carbon treatment, water pollution, and waste water management. Finally, in cluster 5, the most prominent term is "chemical modification," followed by surface property and article.

According to keywords that often appear in the five clusters, several studies elucidate a close relationship between keywords. Scanning electron microscopy is often used to see changes in the surface morphology of activated carbon and activated carbon that has undergone modifications on its surface. This surface morphology can show the nature of its porosity and pore structure. Is the activated carbon included in the micropore, mesopore, or macropore? The nature and structure of these pores will affect the adsorption behavior as well as the adsorption capacity [29], [36]. Activated carbon adsorption is an activated carbon treatment method to absorb dyes, metal ions, and also anions contained in liquid waste. In addition, activated carbon adsorption can also be used in gas absorption, both to absorb toxic gases and to store hydrogen gas. Isothermal adsorption studies using the Langmuir or Freundlich models are frequently used to determine the adsorption capacity of activated carbon [14], [40], [44]. For high valence metals, activated carbon can often not be absorbed optimally. Hence, it is necessary to modify the surface of the activated carbon to increase its absorption. The purpose of the modification to the surface is to change the nature and structure of the surface of the activated carbon so that it has more active groups. Surface treatment in the activated carbon modification process is strongly influenced by surface properties, such as functional groups and catalytic activity [3], [38]. Activated carbon treatment is an alternative that can be used in environmental treatment, such as water treatment and waste water management [7], [32], [43].

4. Discussion

This work has shown that surface modification of activated carbon has been widely carried out to increase the adsorption capacity of activated carbon, and the number of documents published is increasing every year. In contrast to the bibliometric analysis conducted by [19], which emphasizes the modification of adsorbents with ionic liquids to absorb organic pollutants, the bibliometric analysis conducted by Salam, 2019 which emphasizes the application of modified activated carbon to improve water quality, the bibliometric analysis conducted by [2], which emphasizes the adsorption of arsenic metal in drinking water, the bibliometric analysis in this research has a wider scope in terms of the application of modified activated carbon, including the adsorption of volatile organic compounds [3], adsorption of Cd metal ions [12], CO2 gas adsorption [10], [46] adsorption of color and wastewater treatment [33] heavy metal adsorption [4], and radioactive iodide ion adsorption [5]

This bibliometric analysis provides benefits in the form of a reference for researchers who will conduct research on the surface modification of activated carbon as well as its application as an adsorbent. This is important because surface modification of activated carbon can increase adsorption capacity by increasing specific surface area, pore volume, and surface chemical functional groups and decreasing pore size [3], [47], [25]. In addition, it also provides a reference on the thermodynamic aspects of the surface modification of activated carbon, which shows whether the adsorption process is spontaneous and exothermic and how the dominant mechanism is physisorption or chemisorption [10].

Future perspectives for the problem of surface modification of activated carbon will continue to develop. Therefore, therefore an up-to-date bibliometric analysis is needed with an analysis time span of several years to come.

5. Conclusions

This study reports a bibliometric analysis of 262 publications extracted from the Scopus database, which focuses on activated carbon modification. This study presented information related to publication sources, articles, authors, affiliated institutions, publishers, countries, and the most cited themes on modified activated carbon. The results illustrated that in the last 8 years, publications on the surface modification of activated carbon increased significantly, especially between 2019 and 2021. The analysis related to the authors showed that the authors with the highest number of citations were Li X et al. with 148 citations, Ihsanullah et al. with 146 citations, and Heidari A with 139 citations. Meanwhile, the analysis of affiliated institutions shows that the Faculty of Environmental Science and Engineering, Kunming University of Science and Technology, China, is the affiliated institution with the most documents. Elsevier BV and Elsevier Ltd are the publishers who publish the most articles on activated carbon. The countries that publish the most articles on activated carbon modification include the People's Republic of China, India, and South Korea, with the percentages of publications being 25.5%, 9.3%, and 8.7%, respectively. Studies on modified activated carbon mostly focus on the characterization of activated carbon, surface properties, adsorption, and environmental treatment based on the results of keyword analysis. The bibliometric analysis in this study provides relevant information about the surface modification of activated carbon to increase the absorption of harmful metals in environmental treatment.

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