Review

A Bibliometric Review of Adsorption Treatment with an Adsorbent for Wastewater

Nurandani Hardyanti[1], Heru Susanto[2], Fika Aisyah Kusuma[3], Mochamad Arief Budihardjo[3]*

[1]Doctoral of Environmental Sciences, Diponegoro University, Semarang City 50275, Indonesia
[2]Department of Chemical Engineering, Diponegoro University, Semarang City 50275, Indonesia
[3]Department of Environmental Engineering, Diponegoro University, Semarang City 50275, Indonesia

Abstract

Wastewater is produced through the use of clean water and impacts environmental quality; therefore, it must be treated to reduce negative impacts. Adsorption technology is a form of wastewater treatment used to address these problems. The adsorption process can be applied using various materials including graphene-based, metal-organic frameworks (MOFs), carbon nanotubes (CNTs), and carbon-based activated carbon. This journal review aims to determine the applications and development for adsorption technology in wastewater treatment. This review used several software programs including Microsoft Excel to process the data, and VOSviewer to analyze the bibliographic mapping. As a result, 766 articles on adsorption treatment with an adsorbent for wastewater were extracted from the Scopus database and analyzed. The study found that the trend of this topic is increasing each year. Many kinds of adsorbents, such as activated carbon, metal-organic frameworks (MOFs), and graphene-based materials can be used to treat large volumes of wastewater, such as tea waste, dyes, or soybean waste. Moreover, this review showed that many researchers used activated carbon as an adsorbent. In addition, the key contributions of this study are the analysis of relationships between authors, keywords, and journal publishers who discuss this adsorption process and the types of adsorbents used. This can be used as a reference for future studies.

Keywords: adsorbent, adsorption, bibliometric analysis, wastewater

Introduction

Most human activities require water, especially freshwater. Water is necessary for household, industrial, and commercial activities. Using water generates wastewater that may potentially pollute the environment.

Wastewater contains both organic and inorganic matter that may affect environmental quality. Therefore, wastewater must be treated before disposal to prevent environmental impacts. Wastewater can also be recycled using various technologies. Some common wastewater pollutants, such as heavy metals, dyes, and phenolics, require treatment to reduce the risk to human health [1]. Adsorption is one of the most widely applied wastewater treatment methods and has several advantages, including wide application, simplicity, ease of operation, and low energy use [2].

*e-mail: m.budihardjo@ft.undip.ac.id

Adsorption is a technology used to treat and purify wastewater, groundwater, and industrial waste [3]. Adsorption works by changing the adsorbate into an adsorbent [4]. The adsorption process can be applied using various materials including graphene-based, metal-organic frameworks (MOFs), graphene-based, carbon nanotubes (CNTs), and carbon-based activated carbon [5-8]. Many types of adsorbent materials can be used to treat wastewater [9], such as alumina, activated carbon (AC), silica gel, polymeric and biological materials, biomass, zeolite, and clay [10].

Many materials and methods can be used to remove contaminants from wastewater using adsorption treatments. Several factors such as molecular structure, solubility, ionization, temperature, and adsorption substances dissolved in the assortment [11]. The type of adsorbent can affect the quality of absorption, temperature, mineral content, concentration of oxidizing gas, and chemical properties. The correlation between the adsorbate and adsorbent molecules in the adsorption process is a characteristic of the adsorption phenomenon [1].

Vishwakarma [12] explained that adsorption can efficiently and economically overcome soluble and insoluble organic pollutants in wastewater with a pollutant reduction rate of up to 99%. The adsorbent is one of the main factors that must be considered in the adsorption treatment process [13]. Therefore, it is necessary to check the quality of the material to be used, considering factors such as composition of the adsorbent (the presence of functional groups, structure, and pore size), adsorbate (polarity, measure of molecular weight, and its function), as well as environmental conditions (pH, temperature, humidity, and ionic strength) [1]. Usually, adsorption is induced by a desorption process, in which the adsorbate ions move from the surface of the adsorbent into the solution. The amount of adsorbate that is desorbed from the adsorbent can affect the reversibility of adsorption where the more adsorbate is desorbed, the more reversible the adsorption will be [2].

This review discusses the most commonly used adsorption techniques and adsorbents in wastewater treatment. Adsorption has been discussed in recent years and largely does not consider the problems solved in previously published articles. The purpose of this review article is to help the public understand the literature that has been discussed and identify research sectors that can be addressed. Subsequently, combining bibliometric analysis will aid in the easier investigation of certain fields of science [14].

Material and Methods

Experimental

In this study, we collect bibliometric data from Scopus Database which contain review articles, papers, and scientific articles. Scopus is the optimal database for bibliometric analysis and has limited biases. Once the data were collected, bibliometric analysis was carried out. To obtain data before processing, related articles were searched from SCOPUS and accessed on October 22, 2021, by using the main keywords: organic, wastewater treatment, adsorption, and adsorbent. After filtering for English language, final publication stage, and publication date range of 2011–2021, the search results yielded 2736 documents. Furthermore, a selection of journals related to this topic was reviewed. The abstract of each article was read to obtain information about what is discussed in each paper. Finally, A total of 766 articles focusing on adsorption treatment with an adsorbent for wastewater were selected and used as the final sample for the analysis.

Regarding the result of the exported data, different results may have been obtained if the same search were performed on a different date. This is because of the possibility of a record in the SCOPUS. Exported data included the year of publication, author, institution, and cited references. To obtain a scientific map for data analysis, the data were processed using VOSviewer software created by Science and Technology Studies from Leiden University [15]. The mechanism of this software uses the mapping knowledge domain (MKD) method to provide a new way to conduct a literature survey, such as knowledge, which is carried out using data mining, information analysis, scientific measurements, and graphic plots [14]. This software also provides a quick visualization of the current research status, possible evolutions, and emerging trends.

The data were represented on a scientific map and shown by interconnected labels or nodes stating how they are related. A scientific map provides visualization in the form of color, density, and depth, which indicate relationships and the number of related discussions.

VOSviewer also created a network map of scientific publications, journals, researchers, research organizations, countries, and keywords based on the network data shown after processing the data obtained from SCOPUS. Additionally, the connections occurred from co-citation, co-authorship, co-occurrence, citation, and scientific database files [15]. This software was also used to explore large networks involving thousands of nodes. By zooming in on the map, we found which labels were the most recent and which articles may not be visible for a long time. The resulting visualization map shows the existing network, overlay, and data density [15]. Thus, co-occurrence analysis was based on the number of times the keyword was repeated in various articles involving the keywords indicated by the generic keyword index for a particular topic. The higher the occurrence of a keyword, the larger the size of the associated node on the map. The thickness of the link nodes indicates the total amount of time the keywords were considered together in various articles.

The data obtained from SCOPUS included discussion on the adsorption methods used for wastewater treatment and the types of adsorbents selected. Furthermore, the data obtained were processed in VOSviewer and Microsoft Excel to obtain results in the form of a detailed bibliometric review.

Results and Discussion

Brief Review of Previous Literature on Adsorption Treatment, Focusing on the Types of Journals Publishing Relevant Papers

As mentioned in the introduction, many studies discuss the treatment of wastewater using adsorption, which aims to reduce the number of organic substances in wastewater. The adsorption mechanism is divided into several models, such as the linear model, the Freundlich model [16], the Brunauer-Emmett-Teller (BET) model [17], and Langmuir model [18].

A review of the adsorption isotherm model [4] concluded that Langmuir's theory can be derived from the linear, Freundlich, and Sips empirical models. This theory also demonstrates a theoretical monolayer chemical adsorption model. The BET and Aranovich models are theoretical multi-layer adsorption models. An example of the application of the Freundlich isothermal model and the pseudo-second-order model involves the use of a carbon-nanotube-nested diatomite adsorbent (CND-composite adsorbent), which can help remove organic contaminants from shale gas backflow [19]. The results of this study indicate that the CND composite adsorbent had a total organic carbon removal efficiency of 78.91% by involving intermolecular interactions, electrostatic interactions, and hydrogen bonds using CND composite adsorbents as adsorbents for organic compounds.

Carbon-based materials, such as activated carbon, graphene carbon nanotubes, carbon nanofibers, biochar, and carbon aerogels, are adsorbents that can help remove organic and inorganic pollutants from wastewater. The advantages of carbon-based materials include easy production processes, rapid growth of contaminant management, and optimization and improvement of the pollutant removal preparation process [1].

When used in the pre-treatment process, adsorption is combined with other treatment processes, such as combining adsorption with ozonation using natural zeolite and wastewater samples from the tofu industry. The combined process of ozonation and adsorption can degrade pollutants in wastewater, assist the adsorption process of suspended solids, and reduce the Total Suspended Solid (TSS) and Chemical Oxygen Dissolved (COD) contents in wastewater. This process is facilitated by the large content of ozone and zeolite, which play a role in reducing pollutants and increasing hydroxyl radicals.

Owing to the simplicity of the adsorption process, some industries, such as the tea, textile, and soybean industries, apply this treatment to existing wastewater. Several types of wastewater treatment in the tea industry use adsorbents to treat tea leaf waste [20], tea factory waste [21], and process factory-rejected tea [22]. The composition of the tea leaf can help ion exchange, increasing the reduction of metal levels in wastewater [23].

Tea is an economical bio-adsorbent with many benefits, one of which is helping to reduce the concentrations of substances that may be problematic for the surrounding environment [24]. This study also investigated the conversion of tea leaf waste into activated carbon, which is a good adsorbent that can increase the adsorption capacity of the effluent.

Wastewater treatment using adsorption has also been used in the soybean industry, where the high organic content in wastewater must be treated before being discharged into rivers. Irawan et al. [25] discussed the high adsorption achieved by activated carbon in treating tofu wastewater, which resulted in the use of rubber seed shells. They concluded that rubber seed shells can be used as adsorbents in treating tofu liquid waste for COD, BOD, and TSS by focusing on several aspects related to particle size and dosage. The other treatment that can be used to treat tofu wastewater is the Advanced Oxidation Process (AOP), which combines ozonation and zeolite to help eliminate levels of organic and inorganic compounds present in tofu waste.

Moreover, Mohan D. et al. (2014) have discussed the use of adsorption in textile waste treatment. Textile waste consists of dyes and organic substances and must be treated before being discharged into the environment. Therefore, the impact generated after wastewater treatment can reduce the content of dyes and organic substances in the waste. The selected adsorption method used chitosan-based materials. Chitosan is used as an adsorbent to remove dyes, organic substances, and other contaminants present in textile waste [26]. Other positive impacts of chitosan use are low cost, environmental friendliness, easy preparation of materials, biodegradability, and high affinity for dyes and other contaminants.

Analysis of Bibliometric Characteristics of the Articles on Adsorption Wastewater Treatment

Data Processing

Bibliometric analysis was used to evaluate how patterns and trends in academic literature correspond to the topic of discussion [27]. Bibliometric analysis also helps to explore the global scientific literature to determine the pattern and applicability of wastewater treatment using adsorption methods. In this review, we examined research trends related to this topic from 2011 to 2021 by focusing on the level of participation from

journals, reviews, authors, and countries. Therefore, the results of this review indicate future prospects for this topic.

The data used for bibliometric analysis were obtained from SCOPUS. With the stages of filtering, all articles discussing adsorption were selected based on search terms for fields, keywords, titles, and abstracts using the SCOPUS function, i.e. "TITLE-ABS-KEY." Therefore, the first keyword used to obtain data in the search box was "TITLE-ABS-KEY (organic AND wastewater AND treatment AND using AND adsorption). A total of 2736 documents were obtained using a journal selection filter in the final position to limit results to those published in English between 2011 and 2021.

To obtain articles related to the discussion topic, the next step was to filter by reading the abstracts of all the related articles. After reading the abstract, 766 documents matched the topic. Thus, the data obtained are appropriate and there was no decay. The document was then processed in Microsoft Excel for a data cleaning process to ensure that there would be no errors or duplications of data for VOSviewer processing.

Evolution of Publishing Trends on Adsorption from 2011 to 2021

The reader of this review can determine how the adsorption trend is considered by others. After cleaning, the data were processed with VOSviewer to obtain a bibliographic map that was used to analyze the data. This map is shown in Fig. 2. It can be concluded that there are 167, were published in 2021. The fewest articles, 14, were published in 2011. This shows an increasing trend of articles addressing adsorption.

The first use of VOSviewer software demonstrated the productivity of scientific journal publishers from 2011 to 2021. As shown in Table 1, the most productive journal was Chemical Engineering Journal, which published 55 documents related to adsorption in the past 10 years. The publisher of this journal focuses on three aspects of chemical engineering: chemical reaction engineering, environmental chemical engineering, and the synthesis and processing of materials. Other documents cited articles from this publication 1,985 times; thus, this journal was included in list of most frequently cited journals.

The second most productive journal was Desalination and Water Treatment. This publication dedicates its platform to researchers discussing applications of desalination technology, integrated water treatment, wastewater, environmental and energy considerations, water reuse, and other related topics. This United States journal publication was ranked second with a total of 51 publications. Finally, the third ranked journal for adsorption-related papers between 2011 and 2021 was Chemosphere, headquartered in the Netherlands. Chemosphere focused on reviewing

articles related to environmental chemistry, toxicology and risk assessment, treatment, and remediation.

Fig. 1 shows the results of data processing in VOSviewer. The data show how publishers participated in published journals. The map also explains that the size of the nodes is related to the number of articles published, while the thickness of each connecting line indicates the strength of collaboration between them.

Highly Cited Journals from 2011 to 2021

Table 1 shows the order of most cited journal publications from 2011 to 2021. Chemical Engineering Journal publishes After analyzing the calculation by looking for the standard deviation, the second and third point solid waste density values obtained by multiplying five times did not get a significant difference, so weighing four times was considered sufficient. According to Damanhuri and Padmi [28], the density of waste heap in Landfills is 600-1000 kg/m^3, and this means that the results of the passive zone solid waste density sampling are acceptable. the most adsorption papers and was also the most cited with 1985 citations. Meanwhile, the second most cited journal publication was Bioresource Technology, which was cited in 1923 documents. The relationship between the publications in this journal is shown in Fig. 1, in which the thickness of connecting lines indicates the strength of connection between them.The data that were processed from SCOPUS showed that the most cited article over the past 10 years was Organic and inorganic contaminants removal from water with biochar, a renewable, low-cost, and sustainable adsorbent – A review by Mohan et al. [29] published in Bioresource Technology and cited by 1282 articles. This article discusses the use of biochar as an economical and sustainable adsorbent.

Meanwhile, the second most frequently cited article was Rice husk and its ash as low cost adsorbent in water and wastewater treatment [30]. This article, published in Industrial and Engineering Chemistry Research in 2011, was cited in 614 articles. It discussed the use of rice husks as an adsorbent to remove pollutants such as phenols, dyes, organic compounds, heavy metals, organic anions, and pesticides.

The third most-cited article was published in Ecotoxicology and Environmental Safety in 2018 [31]. This article, cited by 347 documents, discussed how different adsorbents can be used to remove emerging contaminants such as hormones, personal care products, and food additives. The three most frequently cited articles were published by different journals and authors in different years.

The latest article was published in 2021, while the most frequently cited article titled A Review on Effective Removal of Emerging Contaminants from the Aquatic System: Current Trends and Scope for Further Research contained a review of the common types of dangerous contaminants, where they come from, and how to detect and treat them. It is necessary to consider

Table 1. Number of publications, publisher country, and number of citations from 2011 to 2021.

Rank	Journal	Number Cited	Total Publications	Subject	Country
1	Chemical Engineering Journal	1985	55	Journal focused on chemical reaction engineering, materials synthesis and processing, and environmental chemical engineering. Aspects of chemical engineering.	Netherlands
2	Desalination and Water Treatment	273	51	This journal focuses on research and application related to the environment, desalination technology, wastewater, energy considerations, water reuse, and other related topics.	United States
3	Chemosphere	936	45	This journal publishes articles and reviews on chemicals in the environment. This publication covers subjects related to environmental chemistry, toxicology risk assessment, treatment, and remediation.	United Kingdom
4	Journal of Hazardous Materials	1387	35	A journal that addresses risk mitigation (Environmental Engineering) and assessing environmental impacts (Environmental Science) in relation to hazardous materials.	Netherlands
5	Journal of Environmental Chemical Engineering	543	34	The focus of this journal is to develop sustainable technologies for wastewater treatment and reuse, water, resource recovery of waste, pollution prevention, nanomaterials for environmental applications, recent developments in green chemistry, sustainability, and environmental safety.	United Kingdom
6	Environmental Science and Pollution Research	358	27	This journal, known as ESPR, publishes news and views on research and technology, hardware and software, education, legislation and regulation, literature, institutions, organizations, and conferences.	Germany
7	Journal of Colloid and Interface Science	949	26	Journal focusing on fundamental principles of colloid and interface science, as well as conceptually novel applications in advanced materials, energy, nanomedicine, catalysis, environmental technologies, and other related fields.	United States
8	Separation and Purification Technology	285	23	A journal dedicated to separation and purification in environmental and chemical engineering for homogenous solutions and heterogeneous mixtures.	Netherlands
9	Water Science and Technology	190	23	Water Science and Technology focuses on the technology and science of wastewater treatment and water quality management.	United Kingdom
10	Journal of Environmental Management	668	21	If the journal publishes papers on environmental systems and improving environmental quality. Work published here must show a distinctive link with environmental management applications.	United States

the adsorption treatment and method used, as well as the cost of treatment. This article was written by Rathi et al. [32] and cited in 41 documents.

The Keywords Analysis

The bibliometric map presented in Fig. 3 explains how widely adsorption keywords are used. The map also shows two nodes in bold print for the words "adsorption" and "wastewater treatment." Therefore, it can be concluded that these words are the main keywords used in this review. Nodes that are close to the main keywords are words that are often used and discussed in articles on adsorption and wastewater.

The words closest to the main keywords are divided into several color segments; in the green segment are activated carbon, wastewater, and water pollutants. In the blue section, there is a relationship with the main keywords that represent factors affecting that adsorption, such as pH, contact time, and hydrogen ion concentration. The red cluster contains words related to chemical influences that can affect adsorption, such as copper, cadmium, and heavy metals.
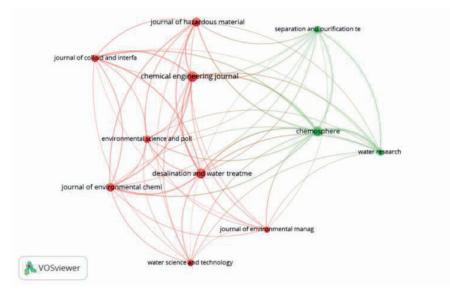
Fig. 1. Bibliometric map showing top 10 journal publications about adsorption.
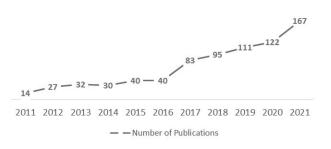

Fig. 2. Number of publications on adsorption in wastewater treatment from 2011 to October 22, 2022.

To know the trend of publications over the past 10 years, the bibliometric map in Fig. 4 shows total repetitions of the word "adsorption," which appeared as many as 25 times in one article. The bibliometric map shows the relationship between the keyword "adsorption" and other studies. The depth of color indicates words that were frequently used by the author to discuss this topic. In other words, words with the deepest color were those most commonly used by writers around the world.

Data processed with VOSviewer indicated that the keyword "adsorption" was discussed 661 times. This
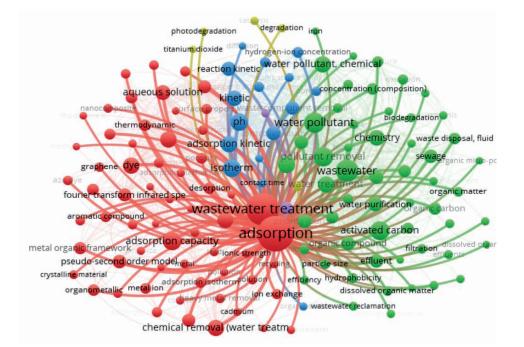

Fig. 3. VOSviewer bibliographic map of the most used and other keywords related to adsorption from publications spanning 2011 to 2021.

Fig. 4. The density of keywords related to adsorption.

large number is because adsorption is the main topic of this review. From the filtered data of 766 articles, the other most-used keyword was "wastewater treatment," which appeared 534 times. The line thickness relationships in each node indicate strong relationships with each author and the relationship between the two words can be concluded because adsorption is an example of wastewater treatment. Thus, if "adsorption" is associated with other keywords, it can be related

with topics related to wastewater treatment, types of adsorbents, or other cases such as those found on bibliographic maps.

Analysis of Journal Author

Based on SCOPUS data, more than 700 articles by various authors and on different topics were published on adsorption between 2011 and 2021. Therefore, this review also obtained data about the authors of these adsorption papers. VOSviewer software was used to identify which writers were the most productive in writing articles about adsorption.

Data analysis showed that Jekel M. published the most papers, 9, which were cited in 302 other documents. Meanwhile, there is a relationship between Guillossou, Le Roux, Mailler, Morlay, Nauleau, Rocher, and Vulliet, who are a team of writers who have published five times with the same title and have been cited in 130 documents.

Table 2. Most published journal author and citation.

Author	Documents	Citations
Jekel M.	9	302
Vigneswaran S.	6	106
Zietzschemann F.	5	201
Ruhl A. S.	5	175
Guillossou R.	5	130
Le Roux J.	5	130
Mailler R.	5	130
Morlay C.	5	130
Nauleau F.	5	130
Rocher V.	5	130
Vulliet E.	5	130
Liu Yang.	5	111
Li Aimin.	5	79
Kandasamy J.	5	58
Wang Jing.	5	46

Conclusions

Adsorption is an example of wastewater treatment in which many variations of adsorbents can be combined to obtain simple, easy, and inexpensive treatment results. The purpose of adsorption treatment is to purify wastewater to reduce environmental pollution. The adsorption process involves changing the adsorbate into an adsorbent. Many kinds of adsorbents, such as activated, carbon, graphene-based, metal-organic frameworks (MOFs), and graphene-based materials can be used to treat large volumes of wastewater, such as tea waste, dyes, or soybean waste.

The type of adsorbent used can be adjusted to the type, characteristics, and costs to be incurred. This review showed that many researchers used activated carbon as an adsorbent. Over time, many studies have introduced new variations in the use of adsorbents. A total of 2736 documents were found in SCOPUS using the keywords "organic wastewater treatment using adsorption;" and these were accessed on October 22, 2021. All articles considered were in the final publication stage and written in English language between 2011 and 2021.

The trend of this topic is increasing each year, but the number of published articles was highest in 2021, with a total publication of 167 documents. The most productive journal for adsorption topics was Chemical Engineering Journal, which had a total of 55 published papers. The most productive writer, according to VOSviewer, is Jekel M., who published 9 documents over 10 years.

Conflict of Interest

The authors declare no conflict of interest.

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