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Literature Review: The Effect of Activated Carbon Adsorption on the Reduction of Iron (Fe) Concentrations in Peat Water

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Abstract

Peatlands in Riau Province have great potential as a water source, but their quality often fails to meet standards due to high levels of organic matter and heavy metals such as iron (Fe), which can pose health risks. This literature review aims to evaluate the effectiveness of various types of activated carbon derived from agricultural waste and biomass in reducing iron (Fe) levels in peat water. The activated carbons reviewed include materials such as empty oil palm fruit bunches, bintaro fruit shells, bamboo stalks, tofu residue, shrimp shells, corn cobs, coffee grounds, and natural zeolite. Findings from various literature sources indicate that the activation process whether physical or chemical, using activators such as H_3PO_4, HCl, and KOH is crucial for increasing the pore volume and surface area of activated carbon to optimize adsorption capacity. Based on the collected data, the highest iron (Fe) removal efficiency reached 99.66% when using corn cob activated carbon activated with 0.25 M HCl at 400°C. Overall, the use of biomass waste as an adsorbent is not only effective and economical in improving peat water quality but also supports sustainable waste management.

1. Introduction

Peatlands play a crucial ecological and hydrological role, one of which is as a highly potential water reservoir to meet the community's clean water needs (Pratiwi et al., 2016). However, in terms of quality, peat water does not yet meet health standards due to its reddish-brown color, high acidity (pH), and high concentrations of dissolved organic matter and heavy metals such as iron (Fe) (Nawan, et al., 2023). Iron (Fe) levels exceeding the threshold not only render the water unsuitable for domestic use but also pose a risk of accumulation in the body, endangering human health in the long term (Said et al., 2019).

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To address this issue, the adsorption method using activated carbon has proven to be an effective and economical technique for reducing iron (Fe) levels. Activated carbon can be obtained from various agricultural wastes and abundant local organic materials. Several previous studies have tested the effectiveness of various activated carbon feedstocks, such as corn cobs, durian peels, and salak seeds, all of which demonstrated significant ability to reduce iron (Fe) levels in peat water (Pujiasih et al., 2019).

Although numerous studies have been conducted on the use of these adsorbents, information regarding the comparative effectiveness and optimization of each type of activated carbon remains scattered and has not yet been systematically reviewed. Therefore, this study aims to comprehensively review the effectiveness of various types of activated carbon in reducing iron (Fe) levels in peat water through a Systematic Literature Review (SLR) approach (Page, M. J et al., 2021). Through this study, it is hoped that the most promising types of activated carbon materials and activation methods can be identified as a scientific basis for the development of practical peat water treatment technologies based on local resources.

2. Materials and Methods

This article was prepared using the Systematic Literature Review (SLR) method, following the PRISMA 2020 guidelines (Preferred Reporting Items for Systematic Reviews and Meta Analyses) (Yudha et al., 2025). This method was used systematically to search for, evaluate, and synthesize various studies on the adsorption of iron (Fe) from peat water using activated carbon derived from biomass/waste. To ensure the transparency and reproducibility of the study, the implementation procedures are outlined in the following steps:

2.1. Literature Review

The secondary data collection process was conducted through a digital search of two main databases, Google Scholar and ScienceDirect, focusing on publications released between 2016 and 2025. The search strategy utilized a combination of keywords. The initial search yielded a total of 1,512 documents, comprising 367 articles from Google Scholar and 1,145 articles from ScienceDirect.

2.2. Inclusion and Exclusion Criteria

To objectively screen for relevant articles, eligibility criteria (inclusion and exclusion) were established as a guide for screening the literature, as presented in Table 1.

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Table 1. Eligibility Criteria (Inclusion and Exclusion)

Criteria	Inclusion Criteria	Exclusion Criteria
Topics & Focus	A study examining the adsorption of iron (Fe) from peat water using biomass/waste-based activated carbon.	Articles that discuss metal adsorption in general or use media other than peat water.
Indexing	Scientific journals indexed in Sinta or Scopus.	Articles not indexed in Sinta or Scopus.
Time Frame	Articles published between 2016-2025.	Articles published before 2016.
Accessibility	Open access article with full text available.	Non open access articles or articles for which the full text is not available.
Language	Use Indonesian or English.	Using a language other than Indonesian or English.

2.3. Article Selection Procedure (Screening Flow)

The article selection procedure is carried out in stages, following the SLR flowchart illustrated in Figure 1:

a. Initial Identification: Collecting a total of 1,512 search results from both databases

b. Initial Screening: An initial check for duplication and suitability was conducted based on the titles and abstracts. This stage yielded 64 potential articles.

c. Second Screening (Eligibility): A total of 64 articles were downloaded to check for full-text availability and accessibility, resulting in 30 open-access articles.

d. Final Selection: 30 articles were thoroughly reviewed for compliance with the inclusion and exclusion criteria. From this process, 8 articles were selected that met all the requirements for further analysis.

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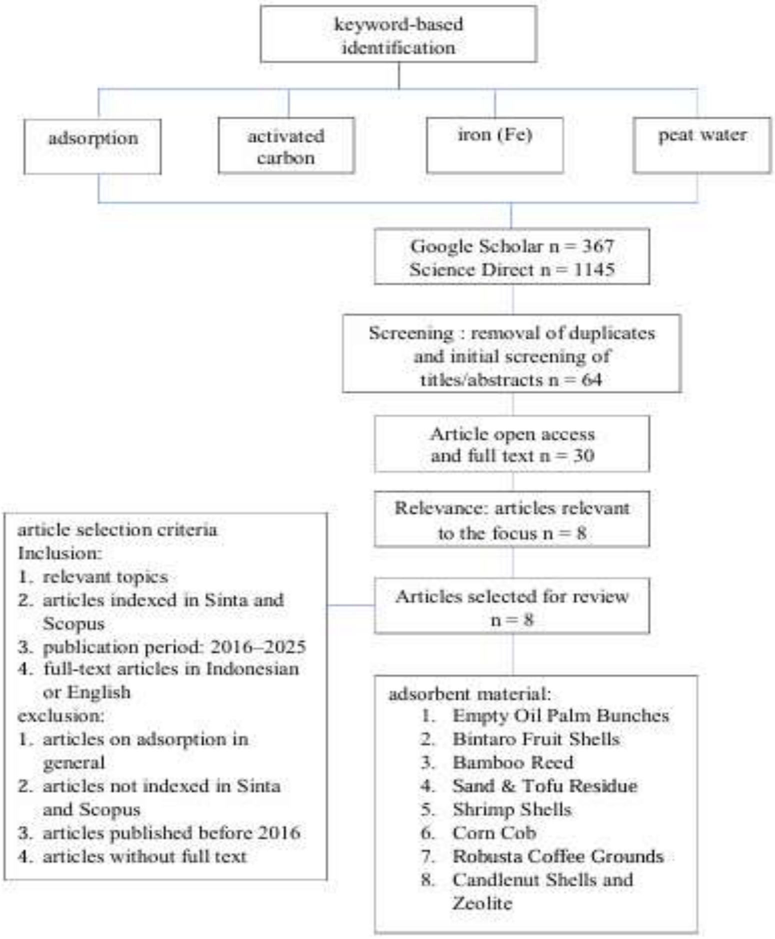

Figure 1. SLR Flowchart

2.4. Data Collection and Extraction Methods

Data from the 8 selected articles were then manually extracted and entered into a data synthesis matrix table. The main components extracted from each article include:

a. Bibliographic information (Author's name and year of publication).

b. Experimental characteristics, including the classification of the activated carbon feedstocks used (e.g., empty oil palm fruit bunches, bintaro fruit shells, bamboo stalks, shrimp shells, corn cobs, etc.).

c. Process parameters, particularly the adsorption activation method used.

d. Experimental results, expressed as the percentage (%) of iron (Fe) removal efficiency.

This structured data was then analyzed descriptively to compare the performance of each type of adsorbent.

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3. Results and Discussions

This study analyzes eight scientific articles that discuss the use of various local materials derived from agricultural waste and biomass as activated carbon precursors for adsorbing iron (Fe) from peat water. A summary of the operational characteristics and iron (Fe) removal efficiency from each study is presented in Table 2.

3.1. Comparative Analysis of Activated Carbon Adsorbents

3.1.1. The Effect of the Type of Adsorbent Raw Material

The characteristics of the main components of the raw material play a crucial role in determining the efficiency of iron (Fe) removal. Based on the collected data, the raw materials can be categorized as agricultural waste/biomass. Corn cob waste from (Salsabila et al., 2023) showed the highest performance with an efficiency of 99.66%, followed by chitosan-based shrimp shells from (Elystia et al., 2022) at 95.65%, and empty oil palm fruit bunches from (Sumila et al., 2023) at 91.0%. The high adsorption capacity of these biomass wastes is attributed to their high content of cellulose, hemicellulose, or chitosan, which are rich in active functional groups capable of capturing metal ions. On the other hand, hard raw materials such as bintaro fruit shells from (Sitanggang et al., 2022) at 83.87% and candlenut shell-zeolite composites from (Susilawati et al., 2025) at 83.2% yielded moderate efficiency. Meanwhile, bamboo culms from (Wahyuni et al., 2022) at 73.03% and Robusta coffee grounds from (Rakhmina et al., 2018) at 65.4% showed lower efficiency. In contrast to carbonized materials, the use of a physical mixture of sand and soybean pulp from (Pratiwi et al., 2016) resulted in the lowest efficiency of only 46.99%. This proves that the lignin and cellulose structures in soybean pulp, without conversion into activated carbon, are unable to bind (Fe) ions.

3.1.2. The Effect of Activation Methods (Chemical and Physical)

Surface modification through a combination of chemical and physical (thermal) activation has proven to be significant in exploring the porosity of adsorbents.

a. The use of 0.25 M hydrochloric acid (HCl) on corn cobs, combined with physical carbonization at 400°C, successfully achieved the highest efficiency (99.66%). The use of strong acid is effective in dissolving mineral impurities and opening micro-pores. However, increasing the HCl concentration to 2 M on Robusta coffee grounds at 450°C actually reduced the efficiency to 65.4%, indicating pore structure damage due to excessive decomposition (over-activation). On the other hand, an environmentally friendly chemical modification using 2% acetic acid and calcium tripolyphosphate (TPP) on shrimp shells (without high-temperature carbonization, only oven drying at 105°C)

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successfully achieved a high efficiency of 95.65% thanks to the formation of specific cross links in the composite.

b. Activation using 10% phosphoric acid (H_3PO_4) at temperatures ranging from 400-600°C resulted in efficiencies ranging from 73.03% to 83.87%. Application of the strong base activator 10% KOH to the candlenut shell–zeolite composite at a high carbonization temperature of 600°C yields an efficiency of 83.2%, where the high temperature triggers synergistic interactions in the formation of carbon matrix pores and the activation of the zeolite structure. Interestingly, the use of 1 N CH_3COONa at a relatively low carbonization temperature of 357°C was able to produce a high efficiency of 91.0%, indicating that this activator is highly efficient in catalyzing the formation of activated carbon without requiring massive thermal energy.

c. Without Activation: The absence of chemical or physical treatment of the sand-tofu-residue composite results in a small surface area, so the adsorption process relies solely on a weak physical absorption mechanism with an efficiency of 46.99%.

3.1.3. Analysis of Optimal Conditions

The optimal conditions for each study provide insights into the cost efficiency, operational time, and sustainability potential of the adsorbents used:

a. Contact Time and Agitation: The fastest adsorption process with optimal results was achieved using shrimp shells, which required only a 30 minute contact time at an agitation speed of 100 rpm to remove 95.65% of the metal (Fe). In contrast, although corn cobs yielded the highest efficiency, their optimal conditions required a very long contact time of up to 48 hours. This is not economically viable when applied on an industrial scale for drinking water treatment.

b. Adsorbent Mass and Concentration: The use of an 8% adsorbent concentration in Bintaro shells and a mass of 6 gr of activated carbon in coffee grounds indicated the absorption saturation limit. Meanwhile, in the zeolite-candlenut composite, the optimal ratio of zeolite (80%:20%) confirms that zeolite acts as the primary ion-exchange agent, supported by the candlenut carbon.

c. Stability and Reusability: From a sustainability perspective, TKKS activated carbon activated with CH_3COONa at 357°C exhibits significant mechanical advantages. This adsorbent reportedly retains 82% efficiency by the fourth usage cycle. This reusability is a crucial factor for longterm applications, as it reduces the costs associated with periodically producing new adsorbents.

3.2. The Mechanism of Iron (Fe) Adsorption on Activated Carbon

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The reduction in iron (Fe) levels in peat water by various types of activated carbon is driven by two main mechanisms: physical adsorption and chemical adsorption.

a. Physical Adsorption: Chemical activation (H_3PO_4, HCl, KOH) and physical activation (furnace at 357°C–600°C) successfully extracted volatile components and formed an extensive network of micro- and mesopores. The massive surface area (500–3000 m²/g) and large pore volume provide geometric space for iron ions (Fe^{2+}) or (Fe^{3+}) to be trapped by diffusion within the carbon matrix.

b. Chemical Adsorption: Peat water is rich in organic substances such as humic acid and fulvic acid, which often bind with iron to form organometallic complexes. Biomass precursors containing lignin, cellulose, or chitosan provide oxygen- and nitrogen-rich active functional groups on the surface of activated carbon (such as carboxyl, hydroxyl, and amine groups). Positively charged iron (Fe) ions in water will undergo electrostatic attraction, ion exchange, or the formation of surface complexes with negatively charged functional groups on the adsorbent surface.

Table 2. Applications of adsorbents made from local materials and their adsorption parameters

References	Materials	Adsorbent Activation Methods		% Efficiency of (Fe)	Optimal Conditions
		Chemistry	Physics		
Sumila et al., 2023	Empty Oil Palm Bunches	400 mL of 1 N (CH_3COONa) solution	carbonized in a furnace at a temperature of 357°C	91.0%	Carbonization temperature 357°C, activation with 1 N CH3COONa (82% efficiency on the 4th use)
Sitanggang et al., 2022	Bintaro Fruit Shells	300 mL of a 10% phosphoric acid (H_3PO_4) solution	carbonized at a temperature of 400°C	83.87%	An 8% increase in adsorbent concentration
Wahyuni et al., 2022	Bamboo Reed	10% phosphoric acid (H_3PO_4) solution	carbonized at 400°C to 600°C	73.03%	Carbonization temperature: 500°C (Highest efficiency)
Pratiwi et al., 2016	Sand & Tofu Residue	Without Activation	Without Activation	46.99%	Use 100% tofu pulp with a contact time of 120 minutes.
Elystia et al., 2022	Shrimp Shells	2% acetic acid and 200 ml of calcium tripolyphosphate (TPP)	Oven drying at 105°C	95.65%	Adsorbent mass: 5 grams, contact time: 30 minutes, and stirring speed: 100 rpm
Salsabila et al., 2023	Corn Cob	HCl (with various activators)	carbonized in a furnace at a temperature of 400°C	99.66%	0.25 M HCl activator, 48-hour contact time with a magnetic stirrer
Rakhmina et al., 2018	Robusta Coffee Grounds	2 M HCl activator	carbonized in a furnace at a temperature of 450°C	65.4%	Using a concentration of 6 grams of activated carbon
Susilawati et al., 2025	Candlenut Shells and Zeolite	10% KOH solution	carbonized in a furnace at a temperature of 600°C	83.2%	A ratio of 80% zeolite and 20% candlenut carbon

3.3. Identifying Research Gaps

Although the eight studies in Table 2 demonstrate that local materials are highly effective in reducing iron (Fe) levels, there are several significant research gaps that have not yet been thoroughly explored:

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a. Peat Water vs. Artificial Solution Matrix: Most articles focus on the efficiency of iron (Fe) removal in isolation. However, peat water has a highly acidic pH (3–4) and a high content of dissolved organic matter (humic acids). These organic compounds have the potential to act as strong competitors for iron (Fe) ions in competing for active sites on the surface of activated carbon (competitive adsorption). Evaluations of the effects of this multicomponent competition remain very limited.

b. Standardization of Optimal Operating Conditions: There are significant variations in operational parameters among researchers (e.g., contact time of 48 hours in Salsabila et al. vs. 30 minutes in Elystia et al.). There are currently no standardized kinetic and adsorption isotherm studies to compare the pure maximum adsorption capacity (qmax) of each of these adsorbents.

c. Specific Textural Analysis: Most of the reviewed literature has not presented comprehensive surface characterization data, such as Brunauer-Emmett-Teller (BET) surface area and the identification of specific functional groups post-adsorption via Fourier Transform Infrared Spectroscopy (FTIR), to demonstrate the type of mechanistic bonding that occurs between the metal (Fe) and the adsorbent surface after the treatment process is carried out

4. Conclusions

This study successfully achieved its objective of evaluating the effectiveness of various activated carbons derived from agricultural waste and local biomass in reducing iron (Fe) levels in peat water. An analysis of 8 literature articles demonstrated that the use of local materials such as empty oil palm fruit bunches, bintaro fruit shells, bamboo stalks, tofu residue, shrimp shells, corn cobs, coffee grounds, and candlenut shells is highly effective and economical as sustainable adsorbents. Both physical and chemical activation processes were found to be crucial in enhancing the porosity and surface area of the materials. Among all the materials studied, the highest Fe reduction efficiency reached 99.66%, achieved using corn cob activated carbon with combined chemical (0.25 M HCl) and physical (400°C) activation. Overall, this study provides a strong scientific basis that biomass waste can serve as an environmentally friendly solution to improve peatland water quality. For future development, further research should focus on optimizing adsorption parameters and exploring other potential local materials that have not yet been extensively studied.

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