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Exploring the Effect of Zeolite/ Activated Carbon Variation in Filtration Media for Peat Water Treatment

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Direct consumption of untreated peat water poses health risks due to the presence of humic substances. Hence, this study examines the influence of different ratios of zeolite to activated carbon on removing contaminants from peat water, utilizing a fixed amount of zeolite (30 g) with varying activated carbon weight (0, 10, 20, 30 g). The highest humic content removal was by column D (30 g zeolite: 30 g activated carbon; 1:1 ratio) at 66.67 %, and similar findings for chemical oxygen demand (COD) and total organic carbon (TOC), single column named as column D remove these water quality indicators at 84.45 % and 65.95 %, respectively. The adsorption of humic acid on carbon's surface is attributed to a combination of electrostatic attraction and surface complex formation.

1. Introduction

Demographic pressures and/or increased per capita consumption have significantly driven global demand for clean water, particularly in developing and low-income countries (Frontuto et al., 2025). Often, depending on certain conditions, this is a multifarious and different problem largely driven by the quality of the treated feed water (Stachurski et al., 2024). Most water-stressed areas have plenty of water resources, including wetlands and peatlands, which comprise about 4-6 % of the whole land surface.Although a variety of wastewater treatment methods have been investigated, conventional sedimentation (Ozaki et al., 2025) and filtration generally achieve only limited removal of organic contaminants, typically around 20–30 % (Chen et al., 2022).
Zeolites are mostly utilized for ion-exchange applications; certain types are regarded as efficient adsorbents for the remediation of groundwater, wastewater (Kumari et al., 2024), and potable water (Chi et al., 2025) . Zeolites are categorized into two types: natural and synthetic and are defined as porous aluminosilicates with crystalline structures (Chi et al., 2025). Orha et al. (2013) evaluated the efficacy of a natural silver-doped zeolite and a composite of multi-walled carbon nanotubes with silver-doped zeolite. The modified particles were tested on adsorption of humic acid at concentration ranging from 5 to 25 mg/L in synthetic water. The adsorption parameters in these investigations were batch settings with a volume of 100 ml, initial humic acid concentration ranging from 5 to 25 mb/L, a dosage of 0.2 g of each adsorbent, a temperature of 25 °C, a pH between 4 and 5, and duration of 1-180 min. Silver-doped zeolite exhibited the higher adsorption capacity (47.9 mg/g), succeeded by multi-walled carbon nanotubes with silver-doped zeolite at 20.2 mg/g. The author did not ascertain a specific reason for this trend. Kinetic study indicated that the adsorption adhered to the pseudo-second order model.
Activated carbon, renowned for its high surface area and exceptional adsorption capacity, is widely employed to capture dissolved organic compounds(Okolie and Okon, 2025) . Zeolites, with their well-defined crystalline frameworks, ion-exchange properties, and thermal stability, further enhance contaminant removal (Liaquat et

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al., 2024). Together, these adsorbents are preferred in advanced treatment processes for their combined chemical versatility, structural tunability, and effectiveness in targeting a broad spectrum of pollutants (Erasga et al., 2024).
To the best of our knowledge, after comprehensive literature review, no study has specifically investigated the removal mechanism of humic acid from peat water using layered activated carbon and zeolite, particularly regarding the individual filtration roles of each layer and their combined effects. This study aims to furnish a theoretical foundation and empirical data to enhance the design, operation and optimization of the zeolite/activated carbon filtration system in peat water treatment.

2. Methodology

This section covers material and experimental setup used in this study.

2.1 Material

Activated carbon and zeolite were acquired from Sigma Aldrich (Germany). Peat water was collected from Beladin, a coastal village along the riverbank in Sarawak, Malaysia. The collected peat water was stored in an air-tight container with ice in an insulating styrene box to preserve the water. For laboratory storage, the collected water was placed in a refrigerator at 4 °C.

2.2 Experimental setup

This study uses multimodal filtration method. The activated carbon constituted the upper layer, while zeolite formed the lower layer. Adsorption occurs at the activated carbon while ion exchange takes place at zeolite. Figure 1 illustrates the experimental configuration multimedia filtering system with mechanism and function.

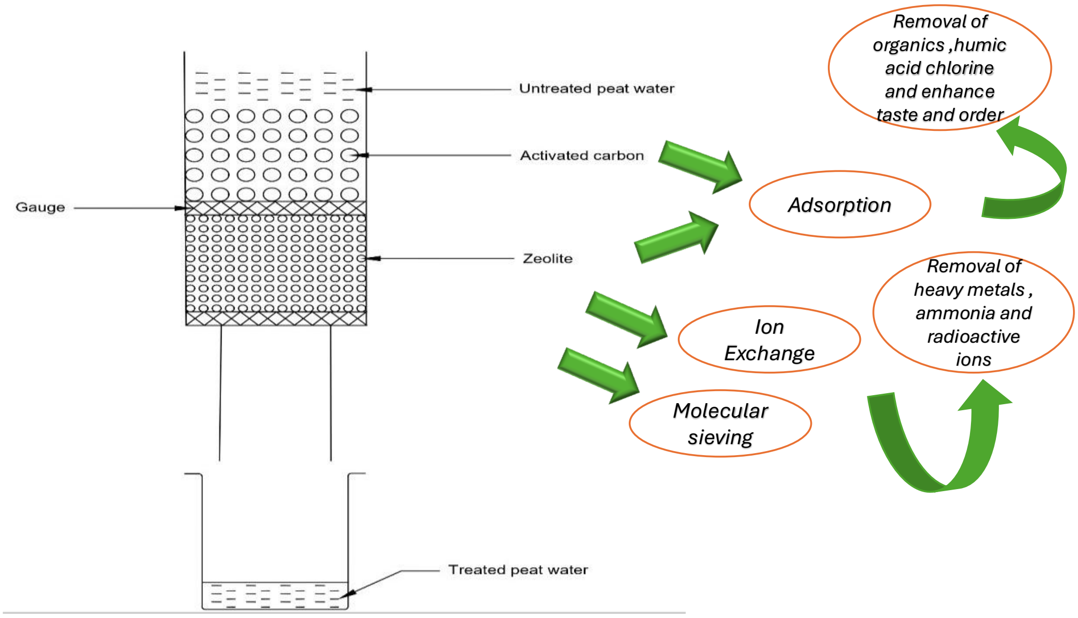

Figure 1: Multimedia Filtration System

The quantification of the filter medium employed in Figure 1 for the treatment of peat water is presented in Table 1. Considering that activated carbon and zeolite are more expensive than other filtration media, minimizing the amount of both materials used can reduce the total costs of the proposed water filtration system. Before utilization, the activation process started for both zeolite and activated carbon. To accomplish this, immerse the zeolite in a 2M hydrochloric acid for 1 hour, then rinse it with distilled water until the pH reaches neutrality. The peat water that enters the column will traverse the filter medium due to the gravitational force, and purified water was acquired for analysis, including (COD), and (TOC). The permeate solution concentration of humic acid was measured at a wavelength of 254 nm with UV–visible spectrophotometer.
Given the relatively high cost of activated carbon and zeolite compared to other filtration media, reducing the quantity of these materials can help lower the overall expenses of the proposed water filtration system. Prior to

use, both zeolite and activated carbon underwent an activation process. Specifically, zeolite was soaked in a 2M hydrochloric acid solution for one hour, followed by thorough rinsing with distilled water until a neutral pH was achieved. As peat water flows through the filtration column under the influence of gravity, the resulting purified water was collected for analysis, including chemical oxygen demand (COD) and total organic carbon (TOC). Additionally, the concentration of humic acid in the permeate was determined using a UV–visible spectrophotometer at a wavelength of 254 nm.

Table 1: Composition of filtration media used to treat peat water

Column	Filter Media	Mass (g)	Percentage (%)	Total
A	Activated Carbon	0	0	100
	Zeolite	30	100	
B	Activated Carbon	10	25	100
	Zeolite	30	75	
C	Activated Carbon	20	40	100
	Zeolite	30	60	
D	Activated Carbon	30	50	100
	Zeolite	30	50	

2.3 Characterization

The SEM-EDX study was performed utilizing a Hitachi TM-3000 (Hitachi, Japan) fitted with an energy dispersive X-ray spectrophotometer (Bruker, United Kingdom) working at an accelerating voltage of 20 kV. FTIR spectra were obtained using a Nicolet iS10 FTIR spectrometer (Thermo Nicolet, USA) over the range of 4,000-400 cm-1 with 32 scans per sample. Carbon samples were diluted with KBr at a ratio of 1:300 to create pellets suitable for FTIR analysis. The microporous surface area was measured using the t-plot technique. To determine the mesoporous surface area, the microporous value was subtracted from the BET surface area. The chemical oxygen demand was ascertained using the COD digestion solution and heated in DRB200 thermostat at 150 °C. for 3 h. The total oxygen content (TOC) levels were ascertained by combusting the samples at 680 °C utilizing a non-dispersive infrared source (Shimadzu, Japan) via the non-purgeable organic carbon method.

1. Result and discussion

This section covers characterization of activated carbon and zeolite effect of the activated carbon to zeolite ratio.

1.1 Characterization of activated carbon and zeolite

The FTIR spectrum of the activated carbon shown in exhibits several absorption bands, indicating the presence of various functional groups on the carbon surface shows in Figure 2 .Significant peaks are observed at wavelengths of approximately 3,743.83 cm^{-1}, 2,561.47 cm^{-1}, 2,430.32 cm^{-1}, 2,158.35 cm^{-1}, 2,017.54 cm^{-1}, 1,971.25 cm^{-1}, 1,867.09 cm^{-1}, and 1,541.12 cm^{-1}, among others. The activated carbon sample comprises the following functional groups: O-H, S-H, C=O, C≡N, C=C, C-II, and O-N. The absorption band observed at 3,743.83 cm^{-1} is indicative of O–H bond stretching, pointing to the presence of hydroxyl groups. Similarly, the peak at 2,561.47 cm^{-1} is associated with S–H bond stretching, suggesting the existence of thiol groups. The FTIR spectrum reveals a diverse array of functional groups integrated into the zeolite framework. Notably, prominent signals at 3,379.29, 3,282.84, and 1,640.00 cm^{-1} are characteristic of O–H stretching vibrations, further confirming hydroxyl group incorporation. These spectral features highlight the complex chemical environment within the zeolite, encompassing both organic and inorganic components.

The activated carbon employed in this study exhibited a unique set of features relative to the examined zeolite. The activated carbon possesses a surface area of 458.271 m^2/g, a pore volume of 0.3553 cm^3/g, and a pore size of 15.5068 Å refer to Table 2. Conversely, the zeolite exhibits a markedly diminished surface area of 0.0670 m^2/g, a substantially bigger pore size of 2677.75 Å, and a notably lower pore volume of 0.08969 cm^3/g. Activated carbon demonstrates superior adsorption properties for smaller molecules due to its diminished pore size and expanded surface area. In contrast, zeolite is more appropriate for larger molecules due to its increased pore size. These inequalities illustrate the superiority of activated carbon.

Figure 2 illustrates the SEM micrograph of the surface of activated carbon and zeolite at a magnification of 3,000x. Figure 2 (a) depicts the porous architecture of activated carbon. It is characterized by its extensive surface area and porosity, evidenced by the prominent and well-defined pores. The pores contain discernible surface material, maybe remnants from the activation process. The inside surfaces of the pores exhibit consistent roughness, indicating a systematic arrangement that facilitates adsorption processes. Activated carbon features bigger and more accurately defined pores, rendering it exceptionally effective for adsorption. Zeolite exhibits a more crystalline and granular texture, as illustrated in Figure 2 (b).

Table 2: Pore properties of activated carbon and zeolite

Filter Media	Pore Volume (cm^3/g)	Pore Size (A)	Surface Area (m^2/g)	Reference
Activated Carbon	0.3553	15.5068	458.271	This Study
Zeolite	0.08969	2677.75	0.0670	This Study

The composite elemental map clearly illustrates the spatial distribution of several components within the zeolite, employing separate colors to denote each element. The elemental maps indicate that silicon and aluminum are uniformly distributed, a characteristic hallmark of the zeolite aluminosilicate framework. The presence of calcium and magnesium suggests the possible occurrence of impurities or subsequent phases inside the sample. The elemental maps and spectra provide a comprehensive representation of the zeolite composition. The uniform distribution of silicon and aluminum aligns with the expected configuration of zeolites. Carbon and oxygen are frequently found in zeolites, both inside the framework and as adsorbed entities. The presence of calcium and magnesium indicates the potential occurrence of contaminants or other phases that may influence the material properties. The maximum intensities in the EDX spectrum reveal that silicon and aluminum are the primary constituents, whereas calcium and magnesium are present in smaller amounts. This comparison highlights the level of purity and the possible functional attributes of the zeolite sample.

(a)

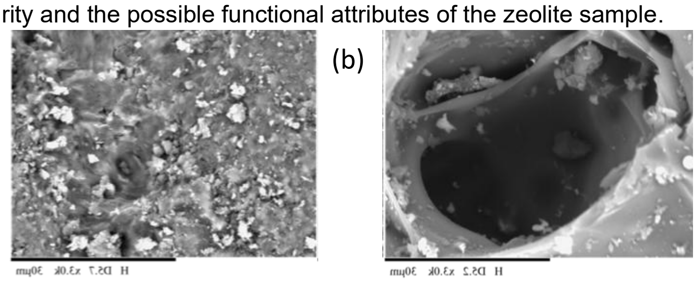

Figure 2: SEM micrograph of a surface of (a) activated carbon and (b) zeolite at magnification of 3,000x

1.2 Effect of the activated carbon to zeolite ratio

Figure 3 presents the humic acid removal following a filtration process employing different quantities of activated carbon and zeolite. Ratios A, B, C, and D recorded rejection rates at 70 min of around 41.4 %, 53.7 %, 60 %, and 66.8 %, respectively. The observed ratio D, comprising 50 g of activated carbon and 50 g of zeolite, is optimal for its efficacy in eliminating humic substances from peat water. A greater proportion of activated carbon enhances its efficacy in removing humic compounds due to its larger surface area compared to zeolite. In the advanced phases of adsorption, a significant quantity of humic molecules is adsorbed onto the zeolite and activated carbon. Subsequent adsorption can occur only if the incoming humic acid locates suitable adsorption sites on the surface and surmounts the electrostatic repulsion between the adsorbed molecules and those intended for adsorption; hence, the adsorption process decelerates in later stages.
Figure 4 depicts the COD analysis of peat water on different ratio.

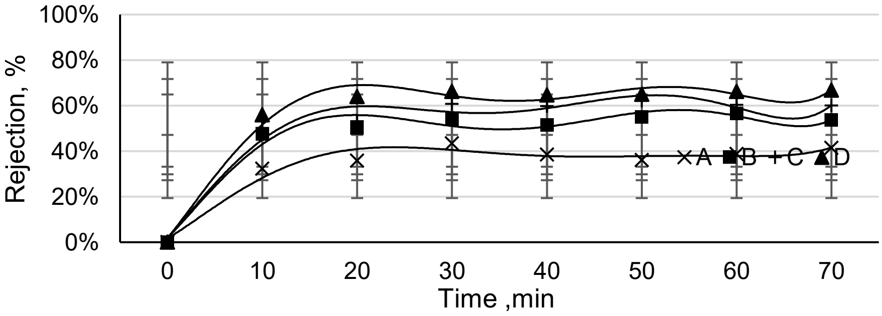

Figure 3: Humic content rejection for different ratios used. A (0 g activated carbon:30 g zeolite), B (10 g activated carbon:30 g zeolite), C (20 g activated carbon:30 g zeolite), and D (30 g activated carbon:30 g zeolite)

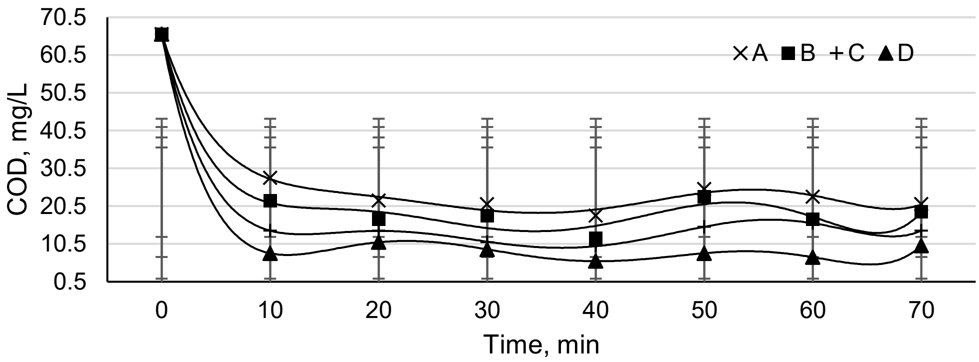

Figure 4: COD analysis of peat water on different dosages. A (0 g activated carbon:30 g zeolite), B (10 g activated carbon:50 g zeolite), C (37.5 g activated carbon:50 g zeolite), and D (50 g activated carbon:50 g zeolite)

The initial COD concentration of raw peat water is 66 mg/L. The COD concentration for ratio A after 70 min is 21 mg/L, resulting in a reduction of 68.18 %. The COD concentration for ratio B after 70 min is 19 mg/L, resulting in a reduction of 71.21 %. Meanwhile, the COD reduction for ratio C and D are 14 and 10 mg/L, respectively. The COD reduction for ratio A is the lowest because zeolite, while recognized for its ion-exchange capabilities and ability to eliminate some contaminants from water, is not particularly good at absorbing organic molecules, which constitute the primary component of COD. The decline escalates from ratio B > C > D, due to the augmentation of activated carbon utilization. Activated carbon possesses a substantial surface area and is highly effective at adsorbing organic molecules. Ratio D exhibits the greatest reduction since it optimizes the adsorption of organic molecules, succeeded by ratio C and B. Figure 5 depicts the TOC analysis of peat water at different ratios of activated carbon to zeolite. Ratio A indicates the lowest TOC reduction, averaging at 4 mg/L, while the highest reduction of TOC was recorded by ratio D at 1 mg/L. The TOC reduction efficiency can be sorted from highest to lowest: ratio D > C > B > A. The removal of TOC by the activated carbon is driven by the adsorption process specifically to the pore site of the adsorbent. For zeolite, due to the nature of the raw water and its method of operation, which requires ion exchange, the removal of organic matter, i.e., TOC, is unfavorable. The zeolite is more potent for the removal of ammonia.

TOC analysis shows that adding more activated carbon (from sample A to D) leads to a faster and greater TOC reduction from around 4.5 mg/L down to 1-2 mg/L within 10–20 min. After this initial drop, TOC levels become slightly unstable over time, due to the gradual oxidation and transformation of intermediate organic compounds.

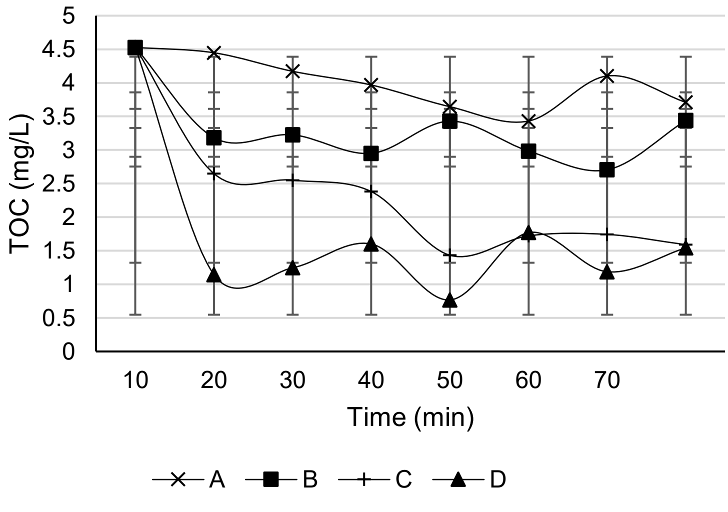

Figure 5: TOC analysis of peat water on different ratio. A (0 g activated carbon:30 g zeolite), B (10 g activated carbon:30 g zeolite), C (20 g activated carbon:30 g zeolite), and D (30 g activated carbon:30 g zeolite)

2. Conclusion

In conclusion, the primary purpose of this study, which aimed to assess the ratio of zeolite to activated carbon in peat water treatment, was successfully achieved. Upon thorough evaluation, it was determined that the ideal ratio is 1:1, comprising 50 % of zeolite and 50 % of activated carbon. This specific combination demonstrated the highest rejection of humic compounds at 66.67 % and the most significant reductions in COD and TOC levels at 84.45 % and 65.95 %, respectively, indicating its efficacy in peat water treatment. Future implications include. Provision of more thorough explanation of why a higher proportion of activated carbon enhances humic acid removal. While the surface area is a contributing factor, additional details, such as the specific interactions between activated carbon and humic substances, would provide a clearer understanding of the adsorption mechanism. Additionally, a statistical analysis of the removal rates across different ratios would help validate this claim.

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