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Research Article

Comparative Study on Acetic Acid Adsorption Using Activated Carbon Derived from Banana and Pineapple Peels

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ABSTRACT

This study compares the adsorption efficiency of acetic acid using activated carbon derived from banana peel (BP-AC) and pineapple peel (PP-AC), aiming to evaluate their potential as sustainable adsorbents for wastewater treatment. Adsorption performance was assessed at various time intervals (5, 10, 15, 30, and 60 minutes). Although BP-AC exhibited a higher surface area (561 m^2/g) than PP-AC (148 m^2/g), both materials demonstrated similar adsorption efficiencies at longer contact times. At 5 minutes, BP-AC showed better performance (3.5%) compared to PP-AC (2.5%), but from 10 minutes onward, both reached comparable removal rates between 4.3% and 5.5%. Surface morphology analyzed by scanning electron microscopy (SEM) confirmed the development of porosity following KOH activation, while energy-dispersive X-ray spectroscopy (EDX) indicated the presence of oxygen-containing functional groups. These functional groups likely contributed to acetic acid adsorption through electrostatic interactions and hydrogen bonding. The findings suggest that factors such as surface chemistry and pore accessibility significantly influence adsorption efficiency, beyond surface area alone. Despite the difference in surface area, the similar performance of BP-AC and PP-AC highlights the importance of functional group interactions in the adsorption process. Overall, the results support the use of banana and pineapple peel-derived activated carbon as cost-effective, eco-friendly adsorbents for acetic acid removal in water treatment applications.

Keywords: Acetic acid adsorption, Activated carbon, Banana peel, Pineapple peel, Wastewater treatment.

INTRODUCTION

Acetic acid is a widely used chemical compound with applications across various industries, including food processing, pharmaceuticals, textiles, and chemical manufacturing. Despite its usefulness, the presence of acetic acid in industrial effluents can pose significant environmental challenges. Its acidic nature can lower the pH of receiving water bodies, leading to harmful effects on aquatic ecosystems such as altered biodiversity, increased metal solubility, and disruption of natural microbial processes [1-3]. Therefore, effective treatment methods are essential to mitigate these environmental risks and ensure regulatory compliance in wastewater management.

Among the various treatment technologies, adsorption is recognized as one of the most efficient and practical approaches for removing acetic acid from aqueous solutions. This method offers several advantages, including operational simplicity, cost-effectiveness, minimal sludge generation, and high removal efficiency even at low concentrations. Activated carbon, in particular, is a widely preferred adsorbent due to its high surface area, well-developed pore structure, and the presence of various surface functional groups that enhance adsorption interactions. Compared to other adsorbents such as zeolites, biochar, metal-organic frameworks (MOFs), and synthetic polymers, activated carbon continues to demonstrate superior performance and flexibility across a wide range of contaminants [3-6].

However, the production of conventional activated carbon often relies on non-renewable and costly raw materials such as coal, peat, or petroleum-based precursors. These sources are associated with high production costs and significant environmental impacts. In response, recent research has increasingly focused on renewable and low-cost

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alternatives, particularly agricultural waste, for activated carbon production. This approach not only provides a sustainable solution for waste valorization but also reduces the environmental burden associated with traditional raw materials [7].

In the context of Thailand, banana and pineapple peels are two abundant agricultural byproducts generated from the processing of two of the country's most important fruit crops [8-10]. These biomaterials are rich in carbon content and are often discarded as waste, making them ideal candidates for conversion into activated carbon. Banana peel-derived activated carbon (BP-AC) typically exhibits a high surface area and microporous structure due to its organic composition and response to activation processes [11-13]. In contrast, pineapple peel-derived activated carbon (PP-AC), which originates from a more fibrous and cellulose-rich material, is expected to offer a different porosity and textural profile that may influence its adsorption behavior [14-16].

Despite the increasing interest in biomass-based activated carbon, a direct comparative study between BP-AC and PP-AC for acetic acid adsorption has not been widely explored. This lack of comparative analysis represents a gap in understanding how the physicochemical characteristics of different agricultural precursors affect adsorption performance, particularly in terms of surface area, pore structure, and surface chemistry [17, 18].

Therefore, the primary objective of this research is to compare the adsorption efficiency of activated carbon derived from banana and pineapple peels for the removal of acetic acid from aqueous solutions. The study involves characterizing both materials using Brunauer–Emmett–Teller (BET) surface area analysis, scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDX) to assess morphological and chemical properties. By examining the relationship between material characteristics and adsorption behavior, the findings aim to contribute to the development of effective, low-cost, and sustainable adsorbents suitable for industrial wastewater treatment applications.

EXPERIMENTAL METHODOLOGY

2.1 Preparation of Activated Carbon

Pineapple peels and banana peels were selected as the raw biomass precursors for the preparation of activated carbon due to their abundance and high carbon content. Initially, the peels were thoroughly washed with tap water to remove dirt, dust, and surface impurities. After washing, they were cut into small, uniform pieces to ensure even drying and carbonization. The prepared materials were then oven-dried at 110 °C for 24 hours to remove moisture content, which is essential for efficient thermal decomposition during carbonization. The dried biomass was subjected to a two-stage carbonization process using a muffle furnace. The first carbonization step was carried out at 200 °C to initiate thermal degradation and convert the biomass into preliminary char. The resulting biochar was then chemically activated to enhance porosity and surface area. Prior to the second carbonization, the biochar was impregnated with a 36.36 wt% potassium hydroxide (KOH) solution at a biochar-to-KOH mass ratio of 3:1. The mixture was left to soak and chemically activate for 1 hour. Subsequently, the second carbonization step was conducted at 600 °C with a controlled heating rate of 10 °C/min, and the target temperature was maintained for 2 hours to complete the activation process. After carbonization, the activated carbon was thoroughly washed several times using distilled water and diluted hydrochloric acid (HCl) to eliminate residual KOH and other soluble impurities. Washing was repeated until the pH of the filtrate reached neutral (approximately pH 7). Finally, the activated carbon was dried in an oven and stored in airtight containers for further adsorption experiments.

2.2 Adsorption of Acetic Acid

The adsorption experiments were conducted using a 0.8 M acetic acid solution as the adsorbate to evaluate the performance of activated carbon derived from banana peel (BP-AC) and pineapple peel (PP-AC). Two stock solutions were initially prepared: 500 mL of 0.8 M acetic acid and 500 mL of 0.5 M sodium hydroxide (NaOH), each in separate volumetric flasks. A total of 10 individual adsorption test setups were organized using additional volumetric flasks—5 flasks assigned for BP-AC and the remaining 5 for PP-AC. In each flask, 25 mL of the acetic acid solution was combined with 0.2 g of the respective activated carbon sample. The mixtures were subjected to continuous agitation using a mechanical shaker set at 300 revolutions per minute (rpm) to maintain uniform mixing throughout the adsorption process. Adsorption was allowed to proceed for specific contact times: 5, 10, 15, 30, and 60 minutes. At

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the end of each time interval, the activated carbon was separated from the solution using standard filter paper. A 15 mL aliquot of the filtered solution was then collected for chemical analysis. The remaining concentration of acetic acid (C_t) in each sample was determined by titration with 0.5 M NaOH using phenolphthalein as an endpoint indicator. This procedure allowed for accurate quantification of the acetic acid not adsorbed onto the activated carbon. The adsorption efficiency at each interval was calculated using Equation (1), which is based on the initial concentration (C_0 = 0.8 M) and the measured concentration at each time point (C_t). This enabled a comparative analysis of the adsorption capacities of BP-AC and PP-AC over time.

$$\text{Efficiency (\%)} = \frac{C(0) - C(t)}{C(0)} \quad (1)$$

This approach allowed for a quantitative assessment of the adsorption performance of activated carbons derived from pineapple and banana peels.

2.3 Material Characterization

To thoroughly evaluate the physical and chemical properties of activated carbon produced from pineapple peel (PP-AC) and banana peel (BP-AC), a series of advanced analytical techniques were employed. Scanning electron microscopy (SEM) was used to examine the detailed surface morphology and microstructure of the materials. Energy-dispersive X-ray spectroscopy (EDX) provided information on elemental composition and distribution across the carbon surfaces. Additionally, Brunauer-Emmett-Teller (BET) surface area analysis was conducted to quantify the specific surface area and porosity. Together, these methods offer a comprehensive understanding of the activated carbons' structure and adsorption potential.

RESULTS AND DISCUSSION

3.1 Acetic Acid Adsorption and Adsorption Efficiency

The adsorption behavior of acetic acid using activated carbon derived from banana peel (BP-AC) and pineapple peel (PP-AC) was systematically investigated over a series of contact times—specifically at 5, 10, 15, 30, and 60 minutes—as shown in **Error! Reference source not found.**. The experimental data demonstrated a consistent and progressive decline in acetic acid concentration throughout the duration of the experiment, confirming the active and ongoing adsorption process facilitated by both types of activated carbon. A particularly notable reduction in concentration was observed within the first 5 to 15 minutes, indicating a rapid adsorption phase. This swift uptake can be attributed to the presence of a large number of accessible and unoccupied active sites on the surface of the activated carbon, which allows for fast interaction with acetic acid molecules. The high initial concentration gradient between the solution and the adsorbent surface provides a strong driving force for mass transfer, enabling acetic acid to diffuse rapidly into the porous structure of the adsorbents. As contact time increases, the rate of adsorption slows, likely due to the gradual saturation of available sites. These observations suggest that both BP-AC and PP-AC are highly efficient in the early stages of the adsorption process, making them effective materials for rapid removal of acetic acid from aqueous environments.

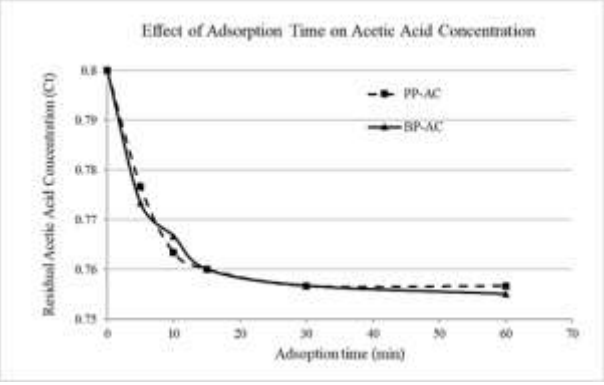

Figure 1 Effect of Adsorption Time on Residual Acetic Acid Concentration for PP-AC and BP-AC

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As the adsorption process continued into the 30- to 60-minute range, a noticeable decline in the adsorption rate was observed for both types of activated carbon. This gradual reduction in rate can be attributed to the progressive saturation of available adsorption sites on the surface of the activated carbon materials. During the early stages, particularly between 5 and 15 minutes, the surface of the activated carbon is rich in accessible active sites, facilitating rapid acetic acid uptake. However, as more acetic acid molecules are adsorbed, these sites become increasingly occupied, leading to a reduced adsorption rate over time. By the 30-minute mark, the rate of acetic acid removal had slowed significantly, and the concentration of acetic acid in the solution began to stabilize. This stabilization indicates that the adsorption process was approaching dynamic equilibrium, where the rate of adsorption and desorption become nearly equal. To quantify the adsorption efficiency at each time interval, Equation (1) was applied, using the initial concentration (C_0) of 0.8 M and the final concentration (C_t) at specific time points. The results, illustrated in **Error! Reference source not found.**, show a clear increasing trend in adsorption efficiency during the early phase, followed by a plateau as equilibrium was reached. At 5 minutes, BP-AC achieved an adsorption efficiency of approximately 3.5%, slightly higher than PP-AC at 2.5%. Over time, both materials continued to adsorb acetic acid, and by the 60-minute interval, the efficiencies of BP-AC and PP-AC reached approximately 5.5% and 5.2%, respectively. These results suggest that although BP-AC exhibited a marginally faster initial adsorption rate, both adsorbents ultimately demonstrated comparable overall adsorption capacities, confirming their potential for effective acetic acid removal from aqueous solutions.

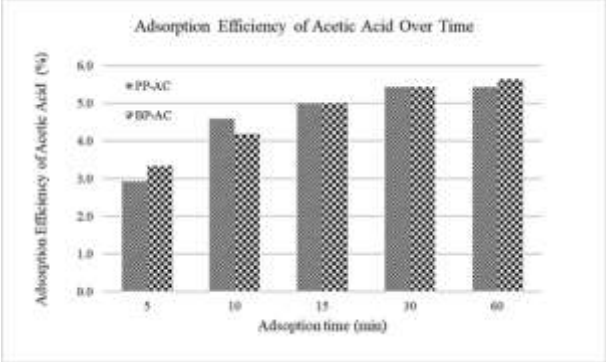

Figure 2 Adsorption Efficiency of Acetic Acid Over Time for PP-AC and BP-AC

The trends observed in **Error! Reference source not found.** and **Error! Reference source not found.** indicate that acetic acid adsorption is governed by multiple factors beyond surface area alone. Specifically, pore structure, surface chemistry, and the presence of functional groups play a critical role in influencing adsorption behavior. Although BP-AC exhibited a higher specific surface area, the comparable adsorption efficiency demonstrated by PP-AC suggests that other parameters, such as pore accessibility and the nature of active sites, significantly affect the adsorption process. The gradual reduction in adsorption rate over time reflects the progressive saturation of available adsorption sites and highlights the impact of diffusion limitations, particularly in microporous structures. These findings emphasize that the efficiency of acetic acid removal depends not only on the extent of surface area but also on the structural and chemical characteristics of the adsorbent. Ultimately, both BP-AC and PP-AC were found to be effective for acetic acid adsorption, with adsorption kinetics primarily influenced by initial surface accessibility and active site availability.

3.2 Relationship Between Acetic Acid Adsorption, BET Surface Area, and SEM Analysis

The adsorption behavior of banana peel-derived activated carbon (BP-AC) and pineapple peel-derived activated carbon (PP-AC) is strongly influenced by their surface area and morphological characteristics, as determined by Brunauer–Emmett–Teller (BET) surface area analysis and Scanning Electron Microscopy (SEM). BET analysis revealed a significant difference in surface area between the two materials: BP-AC exhibited a high surface area of 561 m^2/g, whereas PP-AC showed a considerably lower value of 148 m^2/g. Despite this substantial disparity, both adsorbents demonstrated comparable acetic acid adsorption efficiencies, indicating that surface area alone does not govern adsorption performance.

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SEM images (**Error! Reference source not found.**) offered additional insight into the physical structure of the activated carbon samples. The KOH activation process was effective in enhancing the porosity of both BP-AC and PP-AC, leading to an increased number of potential adsorption sites. However, beyond overall porosity, the nature of the pore structure—specifically pore size distribution and accessibility—plays a critical role in determining adsorption behavior. It is likely that BP-AC, due to its higher surface area, contains a greater proportion of micropores, which may hinder the diffusion of relatively larger acetic acid molecules into the internal structure. Conversely, PP-AC, although possessing a lower surface area, may feature a higher proportion of mesopores or a more open pore network, facilitating better molecular access and transport.

These findings suggest that the effectiveness of an adsorbent is determined by a combination of surface area, pore architecture, and accessibility, rather than surface area alone. Therefore, PP-AC and BP-AC exhibit comparable performance due to the interplay of these structural characteristics.

These results indicate that both surface chemistry and porosity significantly influence adsorption efficiency. The presence of oxygen-containing functional groups, as suggested by EDX analysis, may contribute to electrostatic interactions and hydrogen bonding with acetic acid molecules, further enhancing adsorption. Consequently, while BP-AC benefits from a larger surface area, the pore structure, functional groups, and overall material composition of PP-AC enable it to achieve a similar adsorption efficiency, reinforcing the importance of multiple factors in adsorption performance rather than surface area alone.

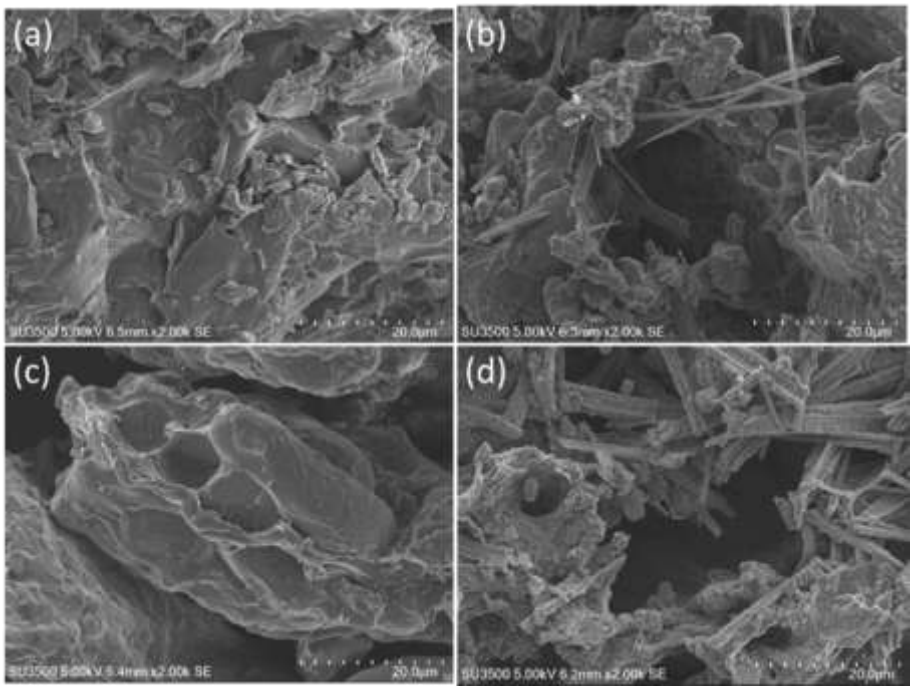

Figure 3 SEM Micrographs of Biochar and Activated Carbon Samples: (a) Pineapple Peel Biochar, (b) Activated Carbon from Pineapple Peels, (c) Banana Peel Biochar, (d) Activated Carbon from Banana Peels

The comparative evaluation of activated carbon derived from banana peel (BP-AC) and pineapple peel (PP-AC) provides valuable insight into the complex and multifactorial nature of adsorption mechanisms. While BP-AC exhibits a considerably higher specific surface area compared to PP-AC, this advantage does not result in a proportionally higher adsorption efficiency for acetic acid removal. This finding emphasizes that surface area alone is not the sole determinant of adsorption performance. Instead, adsorption efficiency is more accurately governed by the combined effects of pore structure, surface accessibility, and chemical functionality. The observation that PP-AC, despite having a significantly lower BET surface area, achieves a comparable adsorption efficiency suggests that a favorable mesoporous structure and the presence of surface functional groups can enhance molecular diffusion and interaction with the adsorbate. This implies that structural and chemical properties may compensate for lower surface area, enabling effective adsorption. These insights highlight an important direction in the design and

optimization of biomass-derived adsorbents. Specifically, material selection should consider not only the capacity to generate high surface area but also the intrinsic chemical composition and morphological characteristics of the biomass. The successful use of banana and pineapple peels—abundant and low-cost agricultural wastes—as precursor materials further supports the viability of sustainable and economically feasible solutions for water treatment. Overall, the findings reinforce the potential for scalable, eco-friendly technologies that utilize agro-waste-derived activated carbon to remove organic pollutants like acetic acid, contributing to both environmental remediation and resource recovery efforts.

CONCLUSION

This study demonstrated that activated carbon produced from banana peel (BP-AC) and pineapple peel (PP-AC) is effective in adsorbing acetic acid from aqueous solutions. The adsorption process showed a rapid uptake during the initial contact period, followed by a gradual approach to equilibrium. Although BP-AC exhibited a considerably higher surface area (561 m^2/g) compared to PP-AC (148 m^2/g), both materials achieved comparable adsorption efficiencies. This suggests that surface area is not the sole determinant of adsorption performance. Instead, characteristics such as pore accessibility, distribution, and surface chemistry play a more influential role. SEM analysis confirmed that KOH activation effectively enhanced the porosity of both materials, while EDX analysis revealed the presence of oxygen-containing functional groups. These functional groups likely contributed to acetic acid removal through electrostatic interactions and hydrogen bonding. The results highlight the critical role of structural and chemical optimization in adsorbent design. Both BP-AC and PP-AC offer promising, low-cost, and sustainable solutions for wastewater treatment, supporting the valorization of agricultural waste.

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