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Banana Stem Based Activated Carbon as a Low-Cost Adsorbent for Pb(ii) Ion Removal

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ABSTRACT

This study aimed to assess the effectiveness of banana stem-based activated carbon as a cost-efficient solution for eliminating lead (II) ions from water-based solutions. Environmental pollution, particularly caused by heavy metal ions in wastewater, poses a significant global challenge. Conventional methods for heavy metal ion removal, such as ion exchange, chemical precipitation, and membrane separation, are not economically viable and require complex processes for treating hazardous sludge. In this study, banana stem is utilised, which is a readily available and inexpensive material, as a precursor for activated carbon. Banana stems were washed, cut into small pieces, and dried to remove moisture. The dried stems were then ground into a powder and sieved to obtain particles of 500 microns in size. The powdered banana stems were mixed with phosphoric acid and deionized water, refluxed at 140°C for three hours to produce char, which was filtered, washed, and carbonized at 400°C in an argon gas environment. The resulting activated carbon was crushed into fine particles, washed until it reached a pH of 6-7, dried, and stored for future use. The resulting activated carbon is characterised using techniques such as Fourier Transform Infrared Spectroscopy (FTIR). The adsorption of lead (II) ions onto the activated carbon was then studied under various conditions, stirring rate, adsorbent dosage, and contact time.

1. Introduction

The immobilization of heavy metals using activated carbon via adsorption is a highly effective and enduring method [1]. Environmental pollution, notably from heavy metal ions in wastewater, is one of the world's most serious problems. Heavy metals are a significant issue in wastewater treatment. These hazardous compounds, found in industrial effluent, municipal sewage, and other sources, can have severe adverse effects on both human health and the environment. Conventional heavy metal ion removal technologies such as ion exchange, chemical precipitation, coagulation and membrane separation are not cost-effective and need complex processes for hazardous sludge treatment. To

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address the issues, this research outlined in this study aims to achieve several objectives. Firstly, it seeks to analyze the impact of chemical activation on the development of pore structure in the produced activated carbon. Additionally, various operating parameters, such as adsorbent dosage, contact time, and stirring rate, will be characterized by the activated carbon derived from banana stems. Lastly, the potential application of banana stem-derived activated carbon in removing inorganic pollutants, specifically its performance in the removal of Pb^{2+} ions, will be evaluated. Activated carbon is commonly utilized for the removal of heavy metal ions from water, including lead (II) ions. Its exceptional capacity for adsorption, owing to its extensive surface area and strong affinity for heavy metals, makes it highly effective in eliminating these ions. While materials like wood, coconut shells, and coal are typically used to produce activated carbon, their availability may be limited or seasonal in certain regions. Therefore, there is a need for cost-effective alternatives in producing activated carbon for heavy metal removal. Banana stems, a readily available waste product generated in many countries, hold promise as a low-cost resource for synthesizing activated carbon. The utilization of activated carbon, particularly derived from biomass wastes, for removing heavy metal ions from wastewater is crucial for several reasons. Firstly, activated carbon serves as an efficient adsorbent material, capable of binding heavy metal ions to its surface and effectively eliminating them from wastewater. Secondly, it is a sustainable and renewable resource that can be produced in large quantities without depleting natural resources or causing harm to the environment. This makes it an attractive option for wastewater treatment. Lastly, activated carbon is non-toxic and biodegradable, contributing to the overall well-being of both human and environmental health. In contrast, many conventional wastewater treatment methods involve the use of chemicals that are hazardous to human health and the environment. By utilizing activated carbon, heavy metal ions can be removed from wastewater without introducing additional harmful substances and improving the efficiency and effectiveness of wastewater treatment.

2. Methodology

The preparation of banana stem to activate carbon involves several steps. Initially, banana stems were obtained from hawker stalls in Kuala Lumpur and Selangor. The stems were thoroughly washed and cut into small pieces. Subsequently, the banana stem pieces were dried in an oven at 150°C for 24 hours to eliminate moisture. Once dried, the stems were ground into a powder using a grinder and sieved to obtain particles of 500 microns. To produce the activated carbon, 25g of the banana stem powder was mixed with 65ml of phosphoric acid (H_3PO_4) and 35ml of deionized water. The mixture was refluxed at 140°C for 3 hours using a Liebig condenser and round bottom flask. After refluxing, the char produced was filtered using filter paper and washed with deionized water to remove excess water. The char was then carbonized at 400°C for 1 hour under an argon gas environment to obtain solid activated carbon. The activated carbon was subsequently crushed into fine particles using a mortar and pestle and washed with deionized water until the pH reached 6-7. The sample was dried and stored in a small container for future use.

The surface morphology of the activated carbon was examined using Field Emission Scanning Electron Microscopy (FESEM). The activated carbon sample was placed in a holder and analyzed using the FESEM to observe its shape, size, and relative particle sizes. Fourier Transform Infrared Spectroscopy (FTIR), conducted with a PerkinElmer Frontier 104968 instrument, was used to identify various functional groups in the activated carbon. FTIR analysis determines the infrared spectrum of the sample and identifies absorption peaks at specific wavenumbers associated with functional groups. X-Ray Diffraction (XRD), performed using a Panalytical Emperial Series 2 instrument, was employed to characterize the crystal structure, crystallite size, and strain of the activated carbon.

This technique helps identify phases or compounds within the material and assess its crystallinity. Finally, the adsorption process was evaluated by measuring the final absorbance of the $Pb(NO_3)_2$ solutions using a UV-vis spectrometer (PerkinElmer Lambda 25). UV-vis spectroscopy measures the change in absorbance as a function of wavelength and provides quantitative information. Lastly, the data was calculated by using the Beer-Lambert Law and tabulated.

3. Result

Figure 1 depicts the FTIR spectrum, which compares the raw banana stem (RBS) with the activated carbon banana stem (ACBS). The analysis reveals the presence of multiple absorbance bands in each sample. Both spectra show strong peaks in the range of 3000 to 3600 cm^{-1}, which can be attributed to the stretching of OH bonds, and features between 1750 and 1400 cm^{-1}, likely indicating the stretching of C-O bonds [2-5]. Furthermore, the absorption band between 1300 and 1390 cm^{-1} suggests the stretching of CH_2 bonds, while the band between 1000 and 1050 cm^{-1} corresponds to the stretching of C-O groups [2]. The difference between the activated and raw samples is minimal, indicating that the activator has disrupted the hydrocarbon bond, resulting in changes in the activated carbon [6-8]. The absence of the peak associated with aliphatic CH_2 in ACBS can be attributed to the carbonization process.

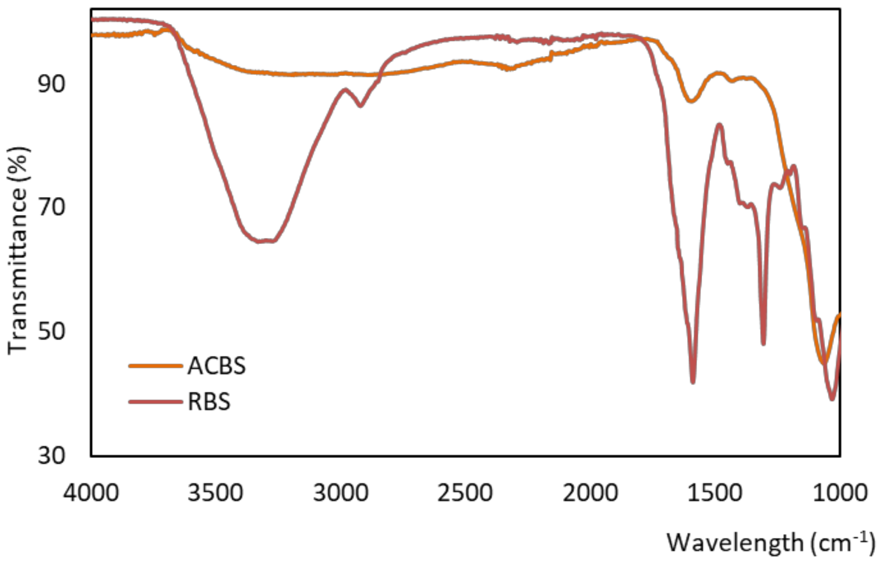

Fig. 1. The FTIR spectra of ACBS and RBS

Table 1 shows the percentage of removal of lead (II) ion by adsorbents is directly related to the dosage of adsorbent used. As the dosage of adsorbent increases, the percentage of lead (II) ions removed from the liquid also increases. This relationship between adsorbent dosage and lead (II) ion removal is known as the adsorption capacity of the adsorbent. Figure 2 illustrates an increasing trend, indicating that the percentage of heavy metal ion removal increases as the amount of adsorbent used increases from 0.05g to 0.2g. Specifically, the percentage removal of heavy metal ions rises from 39.09% to 65.48%. Based on this data, we can conclude that an adsorbent dosage of 0.2g yields the highest removal efficiency as increasing the amount of adsorbent leads to a greater number of active adsorption sites. Consequently, a larger quantity of heavy metal ions can be adsorbed, resulting in higher adsorption capacity and a greater percentage removal of heavy metal ions. Moreover, the presence of additional pores on the biosorption sites facilitates the entry of metal ions into the binding sites. As the amount of adsorbent dosage increases, the percentage of heavy metal ion removal also increases [9].

Table 1
The results of the analysis of adsorbent dosages affecting the percentage of lead (II) ions removal

Adsorbent dosage / g	Final Concentration/mg L^{-1}	Absorbance / A	Removal Percentage / %
0.05	0.83	3.05	39.09
0.10	0.68	2.49	50.27
0.15	0.64	2.34	53.28
0.20	0.47	1.73	65.48

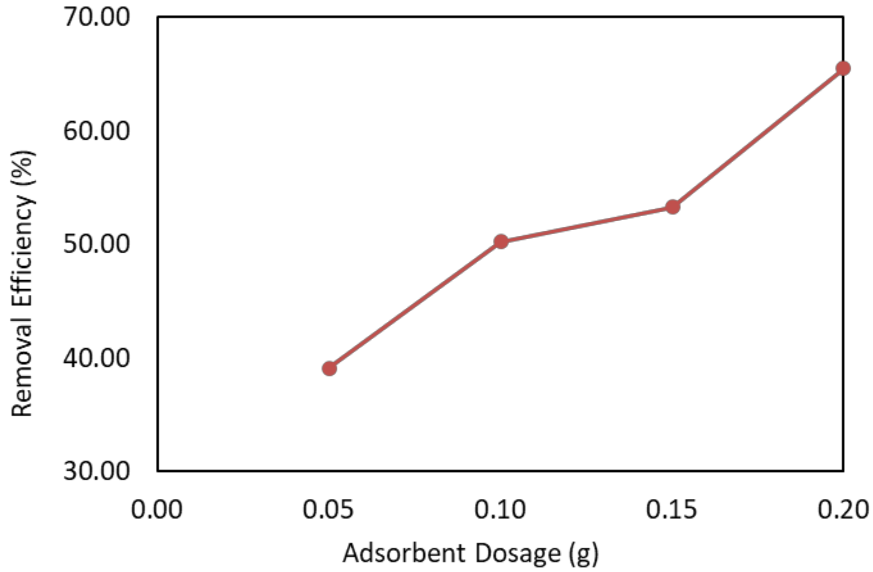

Fig. 2. Removal efficiency of lead (II)ions against the adsorbent dosage

Table 2 shows the percentage of removal of lead (II) ion in aqueous solutions is dependent on a variety of factors, one of which is the stirring rate. As the stirring rate increases, the percentage of lead (II) ions removed from the solution also increases. The graph presented in Figure 3 depicts the relationship between the stirring rate and the removal efficiency of heavy metal ions. Upon analyzing the graph, it can be observed that the percentage of Pb ion removal experiences fluctuations as the stirring rate varies. Specifically, for stirring rates between 150 and 200rpm, the removal efficiency of Pb ions increases from 53.10% to 63.69%. However, at 300rpm, the removal efficiency decreases to 57.92%. This trend can be explained as at lower stirring rates, the heavy metal ions fail to disperse rapidly enough to effectively bind with the active sites on the adsorbents. As a result, the removal efficiency is relatively lower. On the other hand, at higher stirring rates, the heavy metal ions move vigorously due to the rapid stirring, which limits the amount of time they must interact with the active sites on the adsorbents. Consequently, the removal efficiency decreases. Based on the data provided, it can be inferred that the optimum stirring rate for achieving the highest removal efficiency of heavy metal ions is 200rpm. This is because, at this stirring rate, the removal efficiency reaches its peak value of 63.688%. As the stirring rate increases beyond a certain point, the percentage of lead (II) ion removal will not increase significantly [10-14].

Table 2
The results of the analysis of stirring rate affecting the percentage of lead (II)ions removal

Stirring rate/rpm	Final Concentration/mg L^{-1}	Absorbance / A	Removal Percentage / %
150	0.64	2.35	53.10
200	0.50	1.82	63.69
250	0.51	1.88	62.47
300	0.58	2.10	57.92

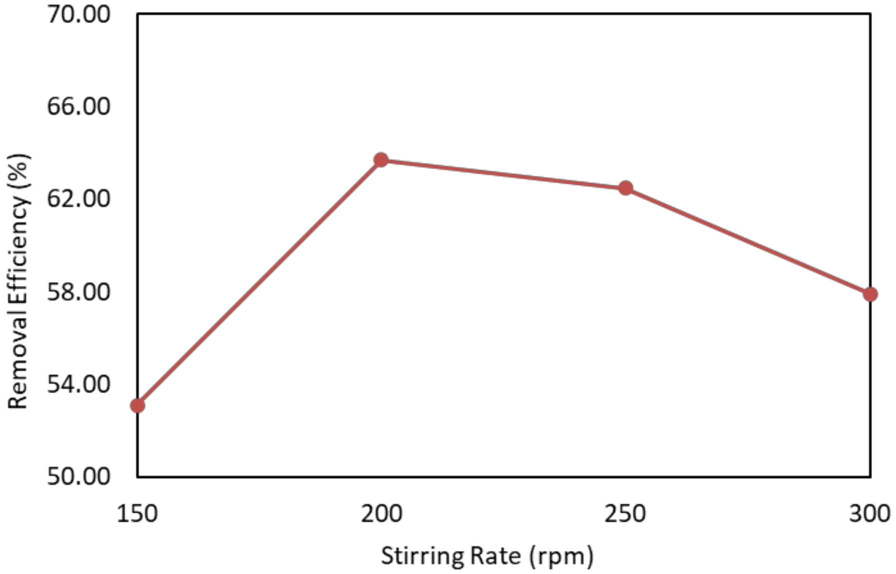

Fig. 2. Removal efficiency of lead (II) ions against the stirring rate

Table 3 illustrates the percentage of removal of lead (II) ion by adsorbents is also related to the contact time between the adsorbent and the liquid. Contact time refers to the amount of time that the adsorbent and the liquid are in contact with each other. As the contact time increases, more lead (II) ions will be removed from the liquid, leading to a higher percentage of lead (II) ion removal. Based on the graph in Figure 4, the removal efficiency of heavy metal ions against varying contact times in which the removal efficiency increased as high as 65.78% as the contact time increased. The percentage of removal reached the peak at the contact time of 30 minutes by achieving the percentage removal of 64.09% which shows the adsorption of heavy metal ions reached equilibrium at 30 minutes of contact. The availability of enough active sites of adsorbent to capture the heavy metal ions increased the rate of removal from 15 to 30 minutes. Therefore, the optimum contact time for the highest removal efficiency of Pb ions is 45 minutes. The availability of enough active sites of adsorbent to capture the heavy metal ions increased the rate of removal from minutes to minutes. Beyond this point, increasing the contact time will not significantly increase the percentage of lead (II) ion removal [10].

Table 3
The results of the analysis of contact time affecting the percentage of lead (II) ions removal

Contact time/ min	Final Concentration/mg L^{-1}	Absorbance / A	Removal Percentage / %
0	0.00	0.00	0.00
15	0.59	2.14	57.13
30	0.49	1.80	64.09
45	0.47	1.73	65.35
60	0.47	1.71	65.79

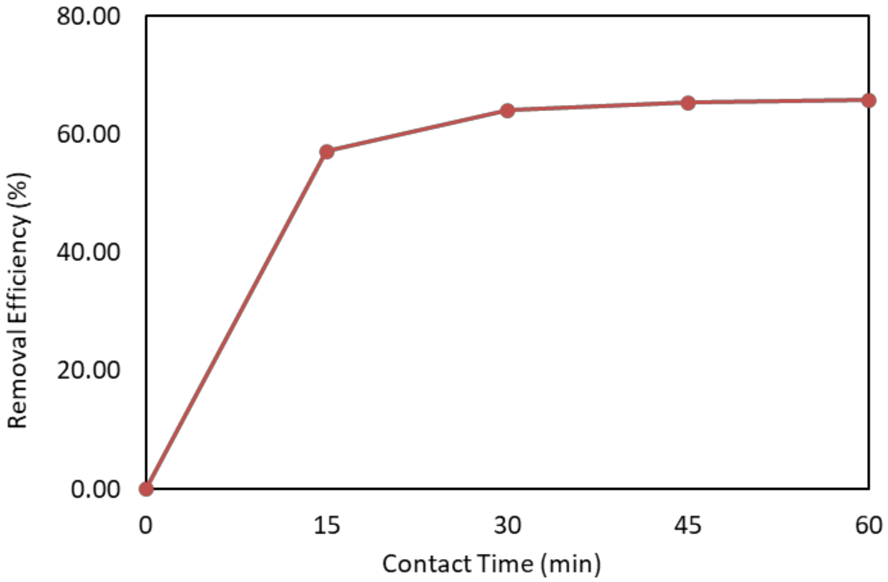

Fig. 4. Removal efficiency of lead (II) ions against the contact time

4. Conclusions

The study aims to produce activated carbon from banana stem powder and assess its effectiveness in removing heavy metal ions. The banana stem powder was activated using H_3PO_4, and both the untreated powder and activated carbon were characterized using FTIR. The efficiency of heavy metal ion removal was investigated by analyzing the impact of initial contact time, adsorbent dosage, and stirring rate. These factors were analyzed to assess their influence on the removal efficacy of heavy metal ions using the activated carbon derived from banana stem. This research has the potential to contribute to the development of more sustainable and cost-effective solutions for water treatment.

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