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Banana Peel Adsorbent to Reduce the Concentration of Lead and Cadmium Metal Pollution in Landfill Leachate

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Abstract

Banana peels can be a valuable adsorbent for reducing heavy metals in water. This study investigated the effect of chemical activators on Nipah banana peel (*Musa acuminata balbisiana*) on their ability to reduce Pb and Cd metals in landfill leachate. Before the adsorption test, the banana peels were treated with a different chemical activator, including detergent, NaOH, KOH, and H_3PO_4. The results showed that H_3PO_4 adsorbs relatively high amounts of metals (Pb- 75.8%, Cd-18.491%) in landfill leachate among these activators. FTIR analysis showed that banana peels treated with H_3PO_4 produced sharper carbonyl or carboxyl group peaks. These groups are very influential in the metal adsorption process. SEM-EDS analysis of the H_3PO_4-treated banana peels showed an increase in carbon and oxygen elements in the banana peels and changes in the pore surface that enhanced the adsorption process on Pb and Cd metals. From this study, banana peels activated with H_3PO_4 showed great potential to be developed into adsorbents to reduce heavy metal concentration.

1. Introduction

Landfill leachate is formed when water passes through landfills through rain and seeps through waste piles. Landfill leachate is often found to be toxic and produces pollutants that pose a potential threat to the surrounding environment and ecosystem [1]. Among the various contaminants found in leachate, heavy metal ions are the most toxic and hazardous [2]. Heavy metals such as cadmium, mercury, zinc, chromium, arsenic, and lead are among the contaminants found in landfill leachate. Due to their non-biodegradability, mobility, and toxicity, heavy metals in landfill leachate are a major source of concern [3].

High concentrations of lead (Pb) and cadmium (Cd) were found in landfill leachate [4]. In an investigation by Chu *et al.* [5], food trash combined with plastic and waste paper in the leachate was shown to be responsible for 95.90% of the Pb and Cd metal contamination. Pb and Cd are ubiquitous non-essential metals constantly released into the environment through human activities and can potentially cause significant harm to the environment and human health. Cd is recognized as one of the most toxic elements with high mobility and bioaccumulation in the environment [6]. As reported in previous studies, bioaccumulation of both Cd and Pb in the human body has been known to cause severe negative impacts on human health, even at low concentrations [7]. Decreasing Pb and Cd concentration levels in landfill leachate is essential to avoid the adverse effects of Pb and Cd heavy metals.

Research is being conducted to use adsorbents derived from agricultural and plantation waste as a more affordable option in the heavy metal degradation process. Adsorbents with low cost and high adsorption efficiency are needed to improve the negative impact of heavy metals on the environment and humans [8]. Adsorbents derived from agricultural and plantation wastes are economical and environmentally beneficial due to their abundant availability, renewability, and affordability. In addition, components such as lignin and cellulose, which are rich in various functional groups such as alcohols, aldehydes, ketones, and carboxylates, are also present in agricultural and plantation by-products. These components are essential in reducing heavy metal concentrations [9]. One type of waste widely generated from community activities is banana peels.

Bananas are widely consumed around the world and are available in abundance. Bananas have the most significant production in West Kalimantan, reaching 1,340,977 quintals in 2022 [10]. The high production of bananas will result in high banana peels as well. The community typically regards banana peels as trash. Banana peels are usually thrown away, even though they have considerable benefits; one is their ability to reduce heavy metal levels as an adsorbent. Several studies have shown that using banana peels as a precursor to adsorbents is more effective than using coconut shells and orange peels [11, 12]. In addition, it also has the benefit of reducing the concentration of lead metal in the environment [13]. However, interdisciplinary research examining the direct application of banana peel adsorbent on wastewater is still limited.

This study used Nipah banana peels as the basic material for making adsorbents and activated by soaking with detergent, NaOH, KOH, and H_3PO_4 to increase the ability of banana peels to adsorb Pb and Cd metals. Furthermore, the adsorbent was directly applied with landfill leachate. Detergent, sodium hydroxide (NaOH), potassium hydroxide (KOH), and phosphoric acid (H_3PO_4) activators were selected as activators to produce adsorbents from banana peels. The use of these activators has proven successful in reducing heavy metal concentrations by about 91-95% for detergent and NaOH [14], about 94-99% for KOH [15], and 99% for H_3PO_4 [16]. Using activators can effectively increase the adsorption power of adsorbents in reducing heavy metal concentrations.

This study focuses on the percent reduction of Pb and Cd metal concentrations in landfill leachate and the comparison of detergent, NaOH, KOH, and H_3PO_4 activators on the adsorption ability of banana peels. This comparison was carried out to discover which activator was the most effective in enhancing the capacity of banana peels to lower the levels of heavy metals Pb and Cd in landfill leachate.

2. Experimental

The research process consists of several stages, starting with landfill leachate sampling, metal content testing, and testing the supporting parameters of landfill leachate. Then, banana peel preparation and activation of banana peel adsorbent using detergent, NaOH, KOH, and H_3PO_4. The activated banana peel adsorbent was applied directly to the landfill leachate and then analyzed.

2.1. Study Location

Leachate samples from the Rasau Jaya Landfill in West Kalimantan were used in this investigation. The landfill has been in operation since 1997 and is still actively used until now. Rasau Jaya landfill leachate is shown in Figure 1 and Table 1.

2.2. Chemicals and Instrumentation

In this research, the materials used were distilled water, $Cd(NO_3)_2.4H_2O$ (Loba), Breeze® laundry detergent, HCl (Merck, 37%), H_3PO_4 (Merck, 85%), Nipah banana peel (*Musa acuminata balbisiana*), KOH (Sigma-Aldrich, 85%), NaOH (Sigma-Aldrich, 98%), Rasau Jaya landfill leachate, and $Pb(NO_3)_2.6H_2O$ (Merck). The banana peel adsorbent was characterized using AAS, FTIR (Shimadzu IRPrestige-21), and SEM-EDS (JSM-IT700HR).

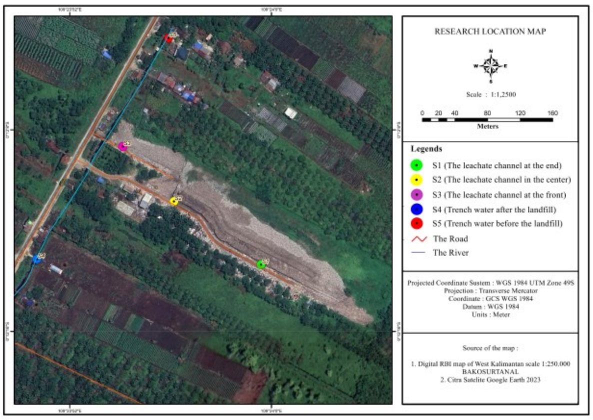


Figure 1. Map of the research location

Table 1. Description of landfill leachate location

Sample code	Distance (m)	Location	Coordinate	
			Latitude	Longitude
S_1	242	The leachate channel at the end	0°12’13.40” S	109°23’59.62” T
S_2	108	The leachate channel in the center	0°12’10.80” S	109°23’56.03” T
S_3	38	The leachate channel at the front	0°12’8.92” S	109°23’54.58” T
S_4	115	Trench water after the landfill	0°12’13.11” S	109°23’50.61” T
S_5	115	Trench water before the landfill	0°12’4.24” S	109°23’55.77” T

2.3. Determination and Sampling of Landfill Leachate Sampling Point

Determination of leachate sample locations around the landfill was done through a purposive sampling method by considering the following factors: availability of leachate water around the landfill and flow from the landfill leachate channel. The results of determining the sampling location obtained five sample location points. Three tree locations were taken from landfill leachate, and two from ditch water around the landfill. Information about the location description can be observed in Table 1.

Sampling was carried out compositely around the location of the five sample points. The leachate sampling time in this study was conducted three days after rainfall. After sampling, Pb and Cd metal tests were first performed to confirm the metal concentrations and determine the leachate samples used. Furthermore, preliminary tests were carried out on the leachate samples determined by the parameters pH, TSS, TDS, COD, and BOD_5. The leachate sample parameter testing results were compared to Government Regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management.

2.4. Preparation and Activator Treatment of Banana Peels

This study used the quantitative method based on previous research [14]. Ripe Nipah banana peels were cut into small pieces (3×3 cm) and washed with distilled water to remove unwanted particles attached to the banana peels. The banana peels were dried for 48 hours in a 50°C oven. The dried banana peel was pulverized and filtered through a 300 μm sieve. The filtered banana peels were macerated using four different activators: detergent, NaOH, KOH [15], and H_3PO_4 [16] for 24 hours. Then, the samples were rinsed and heated in an oven at 50°C for 24 hours.

Mashed banana peels were treated with five different treatments (P) using chemicals (P_0-P_5): P_0-without treatment, P_1-detergent, P_2-NaOH, P_3-KOH, and P_4-H_3PO_4. For treatments P_1-P_2, 10 g of mashed banana peels were soaked in 200 mL each of detergent (pH 8.71) and NaOH (pH 13.12). Ten grams of mashed banana peels were soaked in KOH 1:1 for treatment P_3. For P_4 treatment, 10 g of mashed banana peels were soaked in 40% H_3PO_4 solution (1:1.7).

2.5. Banana Peel Adsorbent Study on Landfill Leachate

Pb and Cd metal solutions were prepared by weighing 0.27 g for Pb and 0.34 g for Cd, respectively, and dissolved in 500 mL. Then, each metal solution was taken in as much as 1 mL and put into 24 mL of landfill leachate at pH 5, along with 0.1 g of fine banana peel. The solution was stirred at a stirring speed (25°C, 120 rpm) for 120 minutes [17]. Then, analytical testing was carried out using atomic absorption spectroscopy (AAS). The wavelengths used to measure Pb and Cd metal ions were 283 nm and 299 nm, respectively. The decrease in the adsorbed metal was determined using Equations 1 and 2 [14].

$$\%\ \text{Reduction of metals Pb and Cd} = \frac{C_0 - C_e}{C_0} \times 100 \quad (1)$$

$$\text{Adsorption capacity of metals Pb and Cd} = \frac{(C_0 - C_e) \times V}{m} \quad (2)$$

Where, C_0 and C_e are the starting and final concentrations in milligrams per liter, respectively, whereas m is the mass of banana peel adsorbent in grams, and V is the volume of solution in liter.

2.6. Statistical Analysis

The data were analyzed using one-way analysis of variance (ANOVA) in Statistical Package for the Social Sciences (SPSS) 2.4 with a 95% confidence level ($p = 0.05$). Tukey's significance test was used to compare the reduction in Pb and Cd metal content in banana peels before and after treatment with detergent, NaOH, KOH, and H_3PO_4. The outcomes were represented by mean values and standard deviations.

3. Results and Discussion

3.1. The Concentration of Pb and Cd Metals at Each Point of Location in Landfill

The concentration of metals in the environment depends on the level of human activity. Solid wastes such as plastics, unused batteries, and paint cans disposed of in landfills can produce Pb and Cd metals [18]. According to Ajah *et al.* [19], pesticides, fertilizers, sawdust disposal, batteries, cement, pyrotechnics, fungicides, rubber, medicines, pigments and dyes, printer toner, herbicides, wax, and paints are all metal sources. Table 2 shows that Pb metal concentration in landfill leachate exceeds the quality standard. At the same time, the attention to the ditch water samples is lower than the quality standard. Unlike the case with Cd metal, its concentration is minimal at each sampling point location, ensuring it does not surpass the predetermined quality standard.

Table 2. The concentration of Pb and Cd metals in landfill leachate

Sample location	Unit	Parameter	
		Pb	Cd
S_1	mg/L	0.14*	< 0.001
S_2	mg/L	0.19*	< 0.001
S_3	mg/L	0.13*	< 0.001
S_4	mg/L	0.02	< 0.001
S_5	mg/L	< 0.02	< 0.001
* quality standard	mg/L	< 0.03	< 0.01

Source: Sucofindo; * above the water quality standard based on PP No. 22 of 2021

Table 3. Landfill leachate characteristics

Parameter	Unit	Result	Class			
			I	II	III	IV
pH	-	8.25	6 - 9	6 - 9	6 - 9	6 - 9
TDS	mg/L	10,096*	1000	1000	1000	2000
TSS	mg/L	2,928*	50	50	400	400
COD	mg/L	635*	10	25	50	100
BOD_5	mg/L	140*	2	3	6	12

Source: Sucofindo ; * above the water quality standard based on PP No. 22 of 2021

At sampling location point S_2, the concentration of Pb metal exceeds that of other sampling points due to the increased accumulation of waste at this site, resulting in a higher concentration of Pb metal. In contrast to sample points S_1 and S_3, where waste buildup is not as significant as at point S_2, the concentration of Pb metal is comparatively lower. According to Sondang *et al.* [20], the more waste that builds up in the landfill, the more leachate is produced [21], stating that high waste buildup increases metal concentrations.

The Cd metal in the five landfill leachate collection points has a very low concentration (Table 2) due to the small amount of waste containing Cd metal contained in the landfill leachate. According to Riza *et al.* [22], high or low concentrations of Cd metal can come from waste generated by human activities. Meanwhile, the concentration of Pb and Cd metals in the ditch water samples before the landfill was lower than after. This indicates that leachate seepage from the landfill may poll the ditch water around the site. According to Imaduddin [23], heavy metal Pb and Cd contamination of surface water around landfills were found due to leachate seepage. However, the Pb and Cd metals concentrations in the landfill leachate were still below the established quality standards.

3.2. Landfill Leachate Characteristics

In this study, the various parameters tested about leachate included acidity (pH,) total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD_5). The results in Table 3 show that the pH of the landfill leachate is alkaline, although still within the established quality standards. However, the concentrations are much higher than the set quality standards for the parameters TDS, TSS, COD, and BOD_5.

The differences in leachate characteristics are due to variations in waste composition and moisture levels and are influenced by seasonal factors such as temperature and rainfall [24]. In addition, leachate characteristics can be affected by the age of the landfill. According to Dabaghian *et al.* [25], the age of the landfill influences its characteristics and composition. As the age of the landfill increases, leachate concentration will decrease due to the waste stabilization process that occurs in the landfill.

3.2.1. Effect of Leachate pH on Metal Solubility

The pH of the landfill leachate was 8.25, which indicates it is alkaline (Table 3). These findings are in line with the research of Oumar *et al.* [26], which revealed that landfill leachate has a pH value of 8.21. According to Adhikari and Khanal [27], the presence of methanogenic bacteria causes the pH value inside the landfill environment to vary depending on the age of the dump. As a result of these bacteria converting accumulated acids into methane and carbon dioxide, the rate of methane gas production will grow [28]. According to Abdel-Shafy and Mansour [29], the pH value increases with the use of acid by methanogenic bacteria.

The age of the landfill leachate plays a vital role in determining the pH parameter. The pH of leachate in young landfills ranges from 5.0 to 6.5, whereas adult leachate ranges from 7.8 to 8.64 [30]. The result was supported by Rikta *et al.* [31], which found that the pH of youth and mature landfills ranged between 5.68 and 8. The pH of landfill leachate influences metal solubility. Neina [32] reported that the solubility of most metals decreases with increasing pH, resulting in lower metal concentrations. Teng *et al.* [33] noted that heavy metal concentrations tend to decrease with age as increasing pH values reduce metal solubility. This study is supported by Tałałaj *et al.* [34], which claimed that increasing pH caused a decrease in Pb and Cd metal concentrations.

3.2.2. Effect of Total Dissolved Solid (TDS) on Metal Solubility

The TDS levels found in the landfill leachate exceeded the established quality standards. The TDS concentration obtained in the landfill leachate was high (10,096 mg/L), as in Table 3. This finding aligns with the research by S. Q. *et al.* [35], which found a TDS concentration of 10,568 mg/L in landfill leachate. The high TDS value is caused by the accumulation of organic and inorganic waste that decomposes in the landfill every day [36]. According to Godwin and Oghenekohwiroro [37], the presence of substantial volumes of anions and cations in leachate caused high total dissolved solids, suggesting the presence of inorganic elements. Higher TDS levels can change leachate's physical and chemical characteristics, resulting in higher TDS values and enhanced toxicity [38]. TDS values are related to the solubility of metals in leachate. According to research by Arinda and Wardhani [39], high TDS concentrations indicated high metal concentrations.

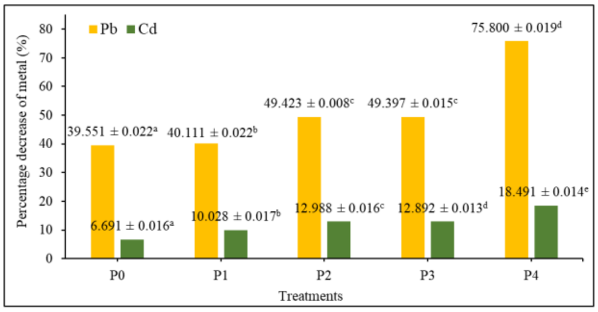
3.2.3. Effect of Total Suspended Solid (TSS) on Metal Solubility

The TSS refers to organic and inorganic particles suspended in water, which is related to light absorption in water [40]. High concentrations of TSS can affect light transmission and aquatic life [41]. Rajoo *et al.* [42] stated that high TSS concentrations inhibit the transfer of sufficient oxygen to aquatic organisms, thus causing digestive disorders in organisms that consume polluted water. The TSS concentration in the landfill leachate was high, reaching 2,928 mg/L (Table 3). This finding is similar to that of Pirsaheb *et al.* [43], who reported that landfill leachate had a TSS concentration of 3,038 mg/L. High TSS values can be caused by waste disposal, such as organic, inorganic, and particulate matter. The TSS value is related to the solubility of metals in the leachate. According to Maniquiz-Redillas and Kim [44], dissolved metals tend to increase as TSS concentration rises. As TSS concentration increases, so does the concentration of fine-sized colloids due to the separation of dissolved and particulate components. These colloidal particles can attach to metals and hold them in solution, thereby increasing the concentration of dissolved metals [44].

3.2.4. Effect of Chemical Oxygen Demand (COD) on Metal Solubility

The COD or the amount of chemical oxygen required for oxidation reactions that release substances in water [45]. The COD concentration in the landfill leachate was high, reaching 635 mg/L (Table 3). A study conducted by Oumar *et al.* [26] found results almost similar to these findings; it was noted that the concentration of COD values in landfill leachate reached 765 mg/L. The increase in COD value was caused by the high content of organic matter in the landfill leachate, which caused an increase in the number of microorganisms and resulted in an increase in COD value.

According to Noerfitriyani *et al.* [46], the COD concentration of waste increased due to the large amount of organic matter. High COD concentrations indicate the presence of organic contaminants that combine with untreated domestic effluents. High COD shows a higher increase in heavy metals because COD suggests a level of organic matter that cannot be biodegraded [47]. An increase in COD concentration also increases the solubility of metals in leachate. Sumantri and Rahmani [47] reported that the higher the COD, the higher the tendency for metal solubility.



Description: symbols (a, b, c, d, e) compare the effect of the percentage of Pb and Cd metal reduction between each treatment. Treatments are given different symbols if there is a significant effect between treatments. The same symbol means that there is no significant effect between treatments.

Figure 2. Percentage decrease of metal Pb and Cd

3.2.5. Effect of Biological Oxygen Demand (BOD_5) on Metal Solubility

BOD_5 is an indicator of biodegradation of biodegradable organic compounds in leachate. It can be seen from Table 3 that the BOD_5 value is high (140 mg/L) in the landfill leachate. This finding aligns with the study of Zin *et al.* [48], which reported that the average BOD_5 value of landfill leachate had a concentration of 146 mg/L. High BOD_5 values can be due to the large amount of residual organic matter in anaerobic digestion. According to Rahmi and Edison [49], the higher the BOD_5 value, the worse the water quality. High BOD_5 values indicate high organic matter content; hence, more oxygen is required for biodegradation. In addition, Lee and Nikraz [50] argued that the BOD_5 value is influenced by the age of the waste material and the type of waste material stockpiled. An increase in BOD_5 concentration increases the solubility of metals in leachate. Maiti *et al.* [51] stated that BOD_5 values are related to metal solubility, where metal concentrations increase with increasing BOD_5 values.

3.3. Comparison Between Activator Treatments in Reducing the Concentration of Metals

Observations using different activator treatments on banana peels reduced the concentration of Pb and Cd metals in landfill leachate (Figure 2). The amount of Pb and Cd adsorbed by banana peel adsorbent became higher after being treated with detergent (P_1), NaOH (P_2), KOH (P_3), and H_3PO_4 (P_4) compared to untreated banana peel (P_0). However, banana peels treated with NaOH and KOH activators showed no significant difference in Pb metal reduction (49.423%-NaOH and 49.397%-KOH). Meanwhile, each activator used for Cd metal provides a significantly different treatment.

The decrease of Pb and Cd metals aligned with their adsorption capacity values. The results of the adsorption capacity of Pb metal without treatment (P_0) and with detergent activator (P_1), NaOH (P_2), KOH (P_3), and H_3PO_4 (P_4) were 1.010 mg/g, 1.024 mg/g, 1.262 mg/g, 1.261 mg/g and 1.935 mg/g, respectively. For each treatment, Cd metal was 0.170 mg/g, 0.254 mg/g, 0.329 mg/g, 0.326 mg/g, and 0.469 mg/g, respectively. The increased adsorption power of banana peel after activation is because the activator can quickly increase the number of functional carboxyl and carbonyl groups on the surface of the adsorption material that can react with Pb and Cd ions [52]. Thus, activation with detergents, NaOH, KOH, and H_3PO_4 allows the formation of many active sites for the adsorption process.

The treatments provided mainly improved the efficiency of Pb and Cd metals. The H_3PO_4 activator resulted in a higher reduction of Pb and Cd metal concentrations than other activators. As observed by Martínez de Yuso *et al.* [53] and Shamsuddin *et al.* [54], the H_3PO_4 activator causes an increase in metal adsorption due to chemical changes on the banana peel surface. In addition, the quantity of acid function is strongly related to the adsorbent to adsorb metal ions. Lantang *et al.* [55] reported that acidic chemical activators increased the adsorption of banana peels compared to essential activators. Ademiluyi and David-West [52] also reported that metal adsorption increased due to more acidic groups when acidic solutions were used rather than alkaline ones for the activation process. Arneli *et al.* [56] reported that H_3PO_4 has higher metal adsorption than NaOH and KOH. In addition, the H_3PO_4 activator increased carbonyl and carboxylic functional groups (Figure 3) and changes in particles and surface pores visible on banana peels (Figure 4).

3.4. Adsorption of Pb and Cd Metal Ions by Banana Peel

Banana peels contain the main structural components of lignin, hemicellulose, and pectin [57]. Banana peels also contain other functional groups, such as -OH, $-NH_2$, -COOH [57]. According to Qiu *et al.* [58], Metal ions are drawn to adsorbent surfaces with functional groups consisting of carboxyl, hydroxyl, amino, and carbonyl. These functional groups either replace hydrogen ions with metal ions or contribute electron pairs in solution to form compounds with metal ions. The results of these tests are supported by FTIR analysis (Figure 3), which reveals the existence of functional groups that contribute to metal reduction in landfill leachate. Some functional groups, such as carboxylic acids, polyphenol hydroxyl groups, and polysaccharides, play an essential role in reducing metal cations. Those functional groups exchange hydrogen ions with metal ions or donate electron pairs to create complexes by metal ions in solution.

Figure 2 shows that Pb adsorption is higher than Cd (Pb > Cd). Pb and Cd have electronegativity values of 2.33 and 1.69, respectively. Therefore, Pb ions have a higher covalent bond strength than low-affinity metal ions such as Cd. Ionic forms are more readily adsorbed by adsorbents as the electronegativity of atoms increases [59]. Thus, the higher electronegativity of Pb ions has higher adsorption than Cd [60]. In addition to greater electronegativity, adsorption for Pb (0.401 nm) and Cd (0.426 nm) is inversely related to the radius of hydrated ions [60].

Arshadi *et al.* [61] stated that the smaller the radius of hydrated ions and the larger their valence, the closer and stronger the heavy metal ions are adsorbed; the larger the hydrated ions, the farther from the surface and the weaker the metal is adsorbed. The radius of Pb hydrated ions is smaller than that of Cd, so it is easy to exchange with other elements through ion exchange, which results in the highest rate of decrease. As shown by the research of Zhou *et al.* [62], in general, the smaller radius of hydrated ions leads to greater electrostatic attraction and greater electronegativity, which results in greater attraction to the opponent ion.

3.5. Characterization of Banana Peel Using FTIR Analysis

Fourier transform infrared spectroscopy (FTIR) effectively describes the relationship between inorganic and organic compounds and analyzes the functional groups of different elements [63]. Figure 3 shows the FTIR spectra of untreated banana peels (P_0), as well as banana peels treated with detergent (P_1), NaOH (P_2), KOH (P_3), and H_3PO_4 (P_4). The interaction between the various elements of the banana peel material is visible in the wavelength range of 3600 to 600 cm^{-1}.

Some peaks show the characteristics of chemical bonds in lipids, proteins, polysaccharides (carbohydrates), and lignocellulose. The absorption peaks at 3425–3410 cm^{-1} are associated with O-H stretching of polysaccharides and lignocellulose and N-H stretching of proteins [64]. The peaks at 2924 and 2854 cm^{-1} bind to C-H vibrations, generally caused by methyl and methylene groups of lipids [65]. In addition, polysaccharides such as cellulose and hemicellulose and phenylpropanoids such as lignin are present [66]. The absorption bands at 1604, 1419, and 1373 cm^{-1} are attributed to the presence of amide groups and protein-related C-H, respectively [67]. The 1249–1026 cm^{-1} peak is associated with C=O bending vibrations [66].

The FTIR results show that the peak intensity at 1735 cm^{-1} wavelength after being treated with the H_3PO_4 activator is clearer and sharper than the other treatments. The peak is related to the C=O vibration of the carbonyl group or carboxylic group [14]. Thus, these results indicate that using an H_3PO_4 activator can produce sharper and clearer absorption peaks to improve the adsorption process on metals. Yang *et al.* [68] revealed that the adsorption process of heavy metals increases with the increasing number of functional groups that have oxygen in them (such as hydroxyl and phenolic groups) on the adsorbent surface. Meanwhile, Kwikima *et al.* [69] stated that carboxyl and hydroxyl functional groups are responsible for binding heavy metals.

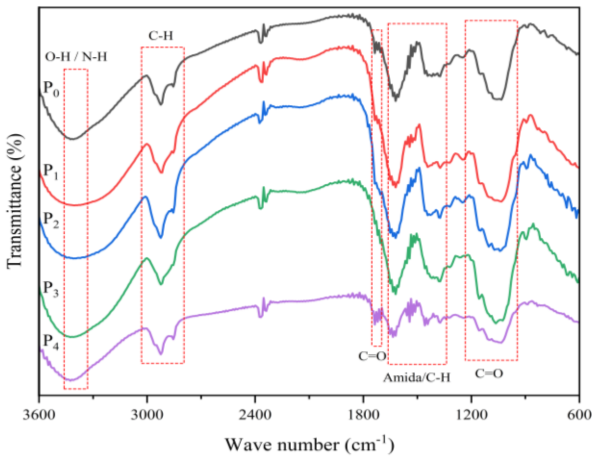


Figure 3. Comparison of FTIR spectra for untreated banana peel (P_0), detergent (P_1), NaOH (P_2), KOH (P_3), and H_3PO_4 (P_4)

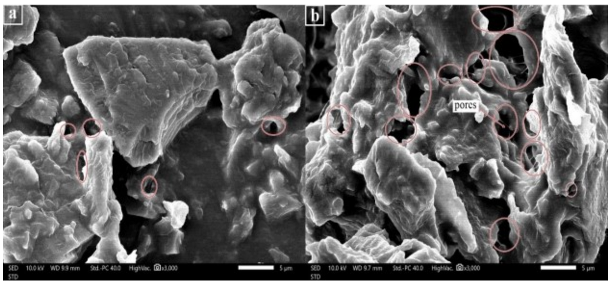


Figure 4. SEM analysis of the banana peel adsorbent (a) without the activator and (b) with the H_3PO_4 activator

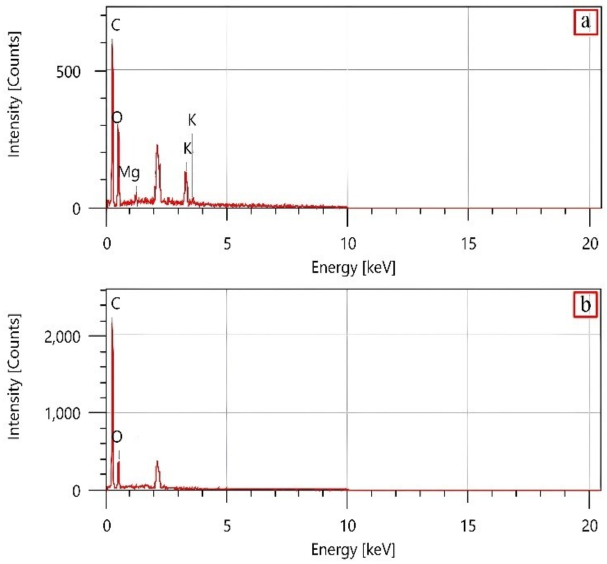


Figure 5. EDS analysis of the banana peel adsorbent (a) without the activator and (b) with the H_3PO_4 activator

3.6. Characterization of Banana Peel Using SEM-EDS Analysis

The scanning electron micrograph (SEM) depicted the banana peel adsorbent both before and after treatment with H_3PO_4, magnified at 3000× resolution. The analysis revealed distinct differences in the morphology of banana peels between the untreated (Figure 4, (a)) and after treatment with H_3PO_4 (Figure 4, (b)), particularly concerning particle distribution and surface condition.

SEM analysis of untreated banana peel (P_0) shows coarse particles and a slightly porous surface area (Figure 4). This is due to the presence of lignin and pectin, which cover the surface area of the banana peel [70]. While the banana peel adsorbent after treatment with H_3PO_4 (P_4), changes appeared in the form of an open and porous surface. According to research conducted by Lee *et al.* [71], an investigation into using banana peel as an adsorbent revealed that activation treatment on the surface of the adsorbent could lead to the oxidation of lignin. The oxidation results in hydroxyl, carbonyl, and carboxyl compounds that can significantly increase the solubility of lignin. As a result, the pore size and surface area of the banana peel increases.

These results are based on the research of Darweesh *et al.* [72], who stated that acid treatment tends to increase the ability to reduce metals by improving the porosity of the adsorbent. Due to the increased porosity, more metal ions will be able to enter and bind to the functional groups in the banana peel. As an outcome, this indicates that banana peel adsorbent after treatment with H_3PO_4 (P_4) has more capacity to decrease metals than untreated banana peels.

EDS analysis showed that the elements C, O, Mg, and K were present in untreated banana peels, but the elements Mg and K disappeared when treated with an H_3PO_4 activator (Figure 5). These results are in accordance with the research of Lavanya *et al.* [73], which stated that Mg and K ions were lost due to the leaching process of these ions. Further research by Li *et al.* [74] suggested the reduction of Mg, Ca, and K elements during adsorption. Carbon and oxygen elements appear due to the presence of -OH and -COOH groups from lignin, pectin, cellulose, and hemicellulose compounds.

According to Tahir *et al.* [75], the high O content is mainly due to the many highly oxygenated banana peel components, such as cellulose, hemicellulose, lignin, and other organic substances. Soltani Firooz *et al.* [76] reported that oxygen is the main element of cellulose material. The structural elements on the surface of the banana peel adsorbent are responsible for enhancing the adsorption process through electrostatic interactions and chemisorption processes.

4. Conclusion

The results showed significant changes ($p \leq 0.05$) between treatments using detergent, NaOH, KOH, and H_3PO_4 activators in reducing Pb and Cd metals. However, NaOH and KOH treatments on Pb metal did not give a real difference. The average values obtained from each activator were Pb-40.111%, Cd-10.028% for detergent, Pb-40.423%, Cd-12.988% for NaOH, Pb-40.397%, Cd-12.892% for KOH, Pb-75.800%, Cd-18.491% for H_3PO_4. H_3PO_4 was chosen as the most effective activating agent for lowering Pb and Cd metal concentrations. These results were associated with increased peaks occurring in carbonyl or carboxyl groups on FTIR analysis. In addition, there was a change in surface area with increased pores and the disappearance of Mg and K impurities in banana peels, as shown in SEM-EDS analysis. This study concludes that activators can increase the effectiveness of metal reduction in landfill leachate by using chemical activators for treatment, and H_3PO_4 is considered a feasible and valuable activator.

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