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Effectiveness of Kepok Banana Peels to Reduce Iron (Fe) in Laboratory Wastewater

Sinardi[1*], Erdin Afida Linnas[2], Andi Nuraliyah[3], Hardimas Prayudi[4]

[1] *Chemical Engineering Study Program, Universitas Fajar, Makassar*
[2] *Center for Standardization and Industrial Services for Plantation Products, Metal Minerals and Maritime, Makassar*
[3] *Chemical Engineering Study Program, Universitas Bhayangkara Jakarta Raya, Jakarta*
[4] *School of Metallurgy and Environment, Central South University*

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KEYWORDS

Kepok banana peel; adsorbent; iron (Fe); laboratory wastewater

ABSTRACT:

Introduction: Kepok banana peels contain fiber, cellulose, and lignin, which play a significant role in the adsorption process. These peels offer advantages as adsorbents due to their low cost, availability, and environmental friendliness. This study explores their potential as an alternative solution for treating Fe-contaminated wastewater.

Objectives: This study aimed to evaluate the effectiveness of Kepok banana peel as an adsorbent for removing iron (Fe) from laboratory wastewater.

Methods: The banana peels were processed into adsorbent material by chemical activation using 1 N HCl and sieving to 100 mesh. Various adsorbent dosages and stirring speeds were tested to determine optimal conditions.

Results: The adsorption process followed the Langmuir isotherm model, indicating monolayer adsorption with strong chemical interactions. Kepok banana peel is proven to be an effective and sustainable adsorbent for reducing Fe levels in wastewater.

Conclusions: The adsorption process followed the Langmuir isotherm model, indicating monolayer adsorption with strong chemical interactions. Kepok banana peel is proven to be an effective and sustainable adsorbent for reducing Fe levels in wastewater.

1. Introduction

Laboratory wastewater is generated from residual chemicals used in student laboratory activities and research. Although the volume of wastewater produced in laboratories is relatively small, its impact on the surrounding environment can be significant. This wastewater may contain various heavy metals, including iron (Fe), zinc (Zn), copper (Cu), chromium (Cr), and lead (Pb), depending on the specific laboratory activities conducted (Saengchut et al., 2024). Heavy metals pose serious risks to environmental sustainability and biological systems, including humans. Because these metals are not biodegradable, they tend to accumulate in the environment, leading to long-term contamination if not treated appropriately (Rachman et al., 2022).

Audina (2017) reported that wastewater from an environmental engineering laboratory had a chemical oxygen demand (COD) of 611.4 mg/L, with metal concentrations of 19.40 mg/L for Fe and 22.90 mg/L for Pb—levels that far exceed permissible limits. According to the Ministry of Environment of the Republic of Indonesia, the maximum allowable concentrations for Fe and Pb in wastewater are 5 mg/L and 0.1 mg/L, respectively.

Thus, treatment methods such as adsorption are needed. Previous studies have shown that, in order to meet environmental quality standards, appropriate pre-treatment and treatment strategies must be applied to laboratory wastewater depending on its composition (Rachman et al., 2022). One sustainable treatment method involves the use of Kepok banana peels (Musa acuminata × balbisiana) as an adsorbent material. The

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adsorption process using banana peels has been demonstrated to effectively reduce heavy metal concentrations in water (Sueb et al., 2016).

Kepok banana peels are rich in fiber, cellulose, and lignin, which contribute significantly to the adsorption process (Budiman et al., 2019; Widyaningsih, 2022). These natural materials offer several advantages: they are abundant, easy to process, cost-effective, and environmentally friendly. Moreover, their large surface area and active functional groups enable efficient binding of heavy metal ions (Erwinsyah et al., 2019; Wardani & Wulandari, 2018). Utilizing these agricultural byproducts not only addresses water pollution but also contributes to the reduction of organic waste accumulation.

Iron (Fe), while essential in small amounts, can be harmful in excess. Consumption of water with high Fe concentrations may lead to nausea, vomiting, diarrhea, or constipation. Chronic iron overload (hemochromatosis) can cause serious damage to the liver, pancreas, and heart. In aquatic environments, high Fe levels disrupt ecological balance, endanger aquatic life, inhibit plant growth, and contribute to eutrophication, leading to decreased dissolved oxygen levels (Hoffman, 2017; Solihin et al., 2019).

The adsorption of Fe ions onto banana peel surfaces occurs through interactions with active functional groups, such as hydroxyl and carboxyl groups (Wardani & Wulandari, 2018; Widyaningsih, 2022). Maximum adsorption is typically achieved under optimal pH, contact time, and adsorbent dosage conditions (Alifaturrahma & Hendriyanto, 2018; Wijayanti & Mahatmanti, 2022).

While various natural materials have been explored for heavy metal adsorption—such as cellulose-based adsorbents, zeolite–chicken feather composites, and coconut shell charcoal—studies focusing on kepok banana peels specifically for Fe removal remain limited. This study aims to fill that gap by investigating the potential of Kepok banana peels as a green and effective adsorbent for Fe in wastewater. This approach offers a promising, low-cost, and sustainable alternative for improving water quality.

2. Objectives

The primary purpose of this research is to establish the efficacy of Kepok banana peels as a sustainable and low-cost adsorbent for removing iron (Fe) from aqueous solutions. To achieve this, the study first details the step-by-step preparation of the adsorbent material. Subsequently, comprehensive characterization of its physical and chemical properties is conducted to understand the underlying mechanisms of adsorption. Finally, the adsorbent's performance is critically evaluated by measuring its capacity to reduce Fe concentrations in contaminated water. Ultimately, this work aims to validate an eco-friendly approach to wastewater treatment by repurposing agricultural waste.

3. Methods

2.1 Equipment and materials

The equipment used in this research included an oven, furnace, analytical balance, pH meter, 250 mL Erlenmeyer flasks, 100 mL beakers, 100 mL volumetric flasks, a spray bottle, 100-mesh sieve, funnel, filter paper, hot plate, magnetic stirrer, Atomic Absorption Spectrophotometer (AAS), and Fourier Transform Infrared Spectroscopy (FTIR) equipment. The materials included Kepok banana peels, 1 N HCl, laboratory wastewater, a 1000 mg/L Fe stock solution, and distilled water.

2.2 Preparation of Kepok Banana Peels

Fresh Kepok banana peels (5 kg) were cleaned, washed with clean water, and cut into small pieces approximately 5 mm in size. The preparation method was adapted from Arifiyana and Devianti (2021).

2.3 Adsorbent Production

The prepared banana peels were dried in an oven at 150°C for 1 hour, then carbonized in a furnace at 350°C for 30 minutes. The resulting charcoal was cooled in a desiccator for approximately 30 minutes.

2.4 Adsorbent Activation

The carbonized banana peels were ground and sieved through a 100-mesh sieve. The sieved material was

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soaked in 1 N HCl for 48 hours for activation and then rinsed repeatedly with distilled water until a neutral pH was reached. The adsorbent was then dried in an oven at 105°C for 1 hour and cooled in a desiccator for 30 minutes.

2.5 Characterization

Characterization was performed using FTIR. The carbonized banana peel powder was mixed with KBr and pressed into pellets. Absorbance was measured in the range of 60–4000 cm^{-1}.

2.6 Variables

The independent variables were the adsorbent dosage (2 g, 3 g, and 4 g) and stirring speed (100 rpm, 200 rpm, and 300 rpm). The dependent variable was the Fe concentration in the treated wastewater. These variations were used to determine the optimal adsorption conditions for Fe (II) ions (Arifiyana & Devianti, 2021; Aulia et al., 2021).

2.7 Adsorption Procedure

Fifty milliliters of laboratory wastewater were placed into 100 mL beakers (25 samples in total). Varying amounts of adsorbent (2 g, 3 g, and 4 g) were added to the samples. Each sample was stirred using a magnetic stirrer for 60 minutes at different speeds (100, 200, and 300 rpm). After treatment, the samples were filtered and the Fe concentration in the filtrate was analyzed using AAS.

The Fe content was measured following the Indonesian National Standard (SNI) 6989.4:2009 using AAS at a wavelength of 248.3 nm. Calibration curves were prepared from Fe stock solutions (0, 0.5, 1.0, and 2.0 mg/L). Samples were digested with 5 mL HNO_3, evaporated on a hot plate to 15–20 mL, filtered, and diluted to 50 mL in a volumetric flask with distilled water.

2.8 Data analysis

The removal efficiency of Fe was calculated using the following equation:

$$\% \text{ Removal} = \% \frac{Co-Ce}{Co} \; x \; 100$$

Where:
Co = Initial Fe concentration (mg/L)
Ce = Final Fe concentration (mg/L)

4. Results

The study evaluated the effectiveness of Kepok banana peel adsorbent—prepared by activation with 1 N HCl and sieving to 100 mesh—in removing iron (Fe) from laboratory wastewater. The initial Fe concentration in the wastewater was 2.2259 mg/L.

5. Discussion

As presented in **Table 1**, the highest removal efficiency was 98.28%, achieved with an adsorbent mass of 4 grams and a stirring speed of 200 rpm. Generally, increasing the adsorbent mass enhanced Fe removal due to the availability of more active binding sites and increased surface area. However, excessive amounts of adsorbent led to a decline in efficiency. This reduction is likely attributed to decreased contact between the solution and the adsorbent surface, which impedes the diffusion of Fe ions into the adsorbent pores.

The adsorbent derived from Kepok banana peel was prepared using 1 N HCl as an activating agent and sieved to 100 mesh. Prior to the adsorption experiment, the Fe content in the laboratory wastewater was analyzed using AAS, yielding a concentration of 2.2259 mg/L, which was used as the initial concentration.

Table 1. Fe Metal Removal using Kepok Banana Peel Adsorbent

Adsorbent Mass (grams)	**Mixing Speed**	**Initial Concentration (mg/L)**	**Final Concentration (mg/L)**	**Allowance Percent (%)**
		Co	***Ce***	***E***
2	100	2.2259	0.3237	85.46
	200	2.2259	0.3369	84.86
	300	2.2259	0.4799	78.44
3	100	2.2259	0.1840	91.73
	200	2.2259	0.0756	96.60
	300	2.2259	0.3570	83.96

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4	100	2.2259	0.1583	92.89
	200	2.2259	0.0382	98.28
	300	2.2259	0.2412	89.16

Table 1 shows that the highest Fe removal efficiency (98.28%) was achieved using 4 grams of adsorbent with a stirring speed of 200 rpm. The increase in adsorbent mass generally led to greater Fe removal, as a larger surface area provided more active sites for ion binding (Alifaturrahma & Hendriyanto, 2018; Wijayanti & Mahatmanti, 2022). However, excessive adsorbent amounts resulted in a decrease in removal efficiency. This may be due to the reduced interaction between the adsorbate and the adsorbent surface, which limits the diffusion of Fe ions into the adsorbent pores (Nurhayati et al., 2020; Widyaningsih, 2022).

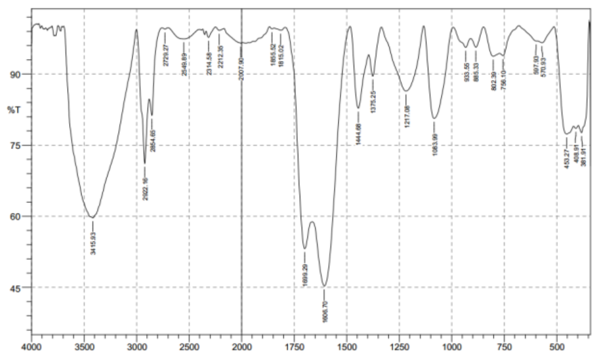

Figure 1. FTIR Spectrum of Kepok Banana Peel Activated Carbon

The chemical characteristics of the activated Kepok banana peel adsorbent were investigated using Fourier Transform Infrared (FTIR) spectroscopy, as presented in **Figure 1**. The FTIR spectrum of the activated carbon derived from Kepok banana peels revealed the presence of key functional groups, including hydroxyl (–OH), aliphatic CH, C=C alkene, and carbonyl (C=O). These functional groups play crucial roles in metal ion adsorption. Hydroxyl groups, found in cellulose and hemicellulose, are responsible for the polar nature of the adsorbent, which promotes interactions with Fe ions (Putra et al., 2019; Zhang et al., 2022). The C=C alkene groups, associated with pectin structures such as galacturonic acid, carry negative charges that can effectively bind positively charged metal ions, thus clarifying the water (Zdunek et al., 2021).

The identification of various functional groups based on their characteristic wavelengths is presented in **Table 2**. These results indicate that the active carbon contained in Kepok banana peel is rich in methyl groups attached to carboxylate groups and hydroxyl groups. So banana peels contain pectin, lignin and cellulose compounds (Savitri et al., 2022).

Table 2. Functional Groups in the FTIR Spectrum Results of Kepok Banana Peel Activated Carbon

Wave Number (cm^{-1})	Functional groups
3415.93	-OH
2992.16	aliphatic CH
2854.65	aliphatic CH
1669.29	C=C alkene
1606.70	C=C alkene
1444.68	-CH
1083.99	CO

The presence of aliphatic CH and –CH functional groups enhances hydrophobic interactions and Van der Waals forces, facilitating the attraction of Fe ions to the adsorbent surface (Arifiyana & Wardani, 2021). These interactions improve the adsorbent's performance in capturing dissolved metal ions from aqueous solutions.

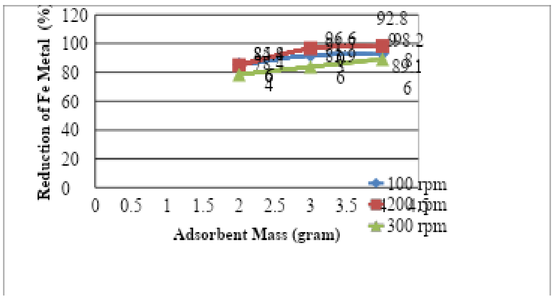

Figure 2. Effect of Adsorbent Weight on Percent Reduction of Fe Metal at Varying Stirring Speeds (100, 200, and 300 rpm)

Based on **Figure 2** obtained optimum Fe metal removal at an adsorbent weight of 4 grams with a mixing speed of 200 rpm, that is 98.28%. The weight of the adsorbent added influences the amount of Fe metal reduction. The greater the amount of adsorbent added, the greater the reduction percentage, and the greater the weight of the adsorbent, the surface area of the adsorbent can be increased (Nurhayati et al., 2020; Wijayanti &

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Mahatmanti, 2022). The increase in the quality of the adsorbent is directly proportional to the increase in the number of particles and the surface area of the adsorbent, increasing the number of metal anion binding sites and an increase in adsorption efficiency (Saleem et al., 2019).

The results of the above study are consistent with previous research by Arifiyana & Devianti (2021). This study used adsorbents from Kepok banana peels to remove Fe (II) from an aqueous solution. In the adsorption process, it was found that an adsorbent mass of 2.5 grams and an initial metal concentration of 60 mg/L gave the highest adsorption and adsorption capacity, at 57.99% and 0.644 mg/g, respectively. FTIR spectra of the adsorbent showed the presence of hydroxyl, carboxyl, and amine groups in Kepok banana peels. This study demonstrated that Kepok banana peels have good potential for removing Fe (II) ions and can be used as an effective adsorbent for removing Fe (II) from water and wastewater at very low concentrations. The larger the adsorbent mass added, the higher the adsorption percentage obtained. This aligns with the prediction that the more surface area available, the more active sites are formed due to the increased adsorbent mass. It indicates that once a certain adsorbent dose is reached, maximum adsorption will be achieved, so the number of ions bound to the adsorbent and the number of free ions will remain constant even with the addition of more adsorbent doses (Karthikeyan et al., 2007).

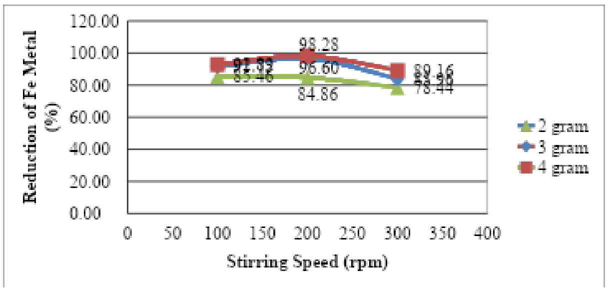

Figure 3. Effect of Stirring Speed on the Percent Reduction of Fe Metal in Adsorbent Weight Variations (2, 3, and 4 grams)

Based on **Figure 3**, the optimal removal of Fe metal was obtained at a stirring speed of 200 rpm and a weight of 4 grams, namely 98.28%. However, at a stirring speed of 300 rpm, the removal rate decreases, because too fast a stirring speed will separate the adsorbent from the adsorbent and make it difficult for the metal ions to bind effectively. Stirring too quickly will quickly damage the structure of the adsorbent, making it difficult for the adsorbent to form strong bonds with iron metal particles, so that the adsorption process is less than optimal (Anom Putra et al., 2019). Due to the high stirring speed, the adsorbates that have adhered and formed flocs will break apart again later.

This study aligns with previous research by Abd-Elaziz et al. (2022), which was conducted to evaluate the potential use of banana peels for the removal of Fe +3 and Pb +2 from aqueous solutions. It was found that heavy metal adsorption on the adsorbent increased as the initial concentration decreased, and the sorption capacity significantly increased with pH levels in the range of 2-8. The study results indicated that the removal of heavy metals, such as Fe^{+3} and Pb^{+2}, from water solutions was highly efficient using banana peels as an adsorbent. The adsorption percentages of Fe^{+3} and Pb^{+2} ions by banana peels were very high. The Langmuir isotherm model best described the experimental data. The maximum sorption capacity was determined to be 79.28 mg/g for Fe^{+3} and 96.58 mg/g for Pb^{+2}. Overall, these findings suggest that banana peels are an environmentally friendly, efficient, and cost-effective bioadsorbent, with excellent potential for removing Fe^{+3} and Pb^{+2} from aqueous solutions. Analysis of changes in adsorbate concentration during the adsorption process to determine the adsorption mechanism using the Freundlich Isotherm equation model and the Langmuir isotherm equation and the optimum removal of Fe metal.

Based on **Figure 4**, graph of the Freundlich isotherm equation for the Kepok banana peel adsorbent at a stirring speed of 200 rpm with a contact time of 60 minutes, the linear equation $y = 0.2402x - 2.7718$ with $R^2 = 0.9581$ is obtained. The Freundlich isotherm equation is an empirical equation used to explain the relationship between the amount of substance adsorbed on the surface of the adsorbent and the concentration of dissolved substances in the solution (Wardani & Wulandari, 2018).

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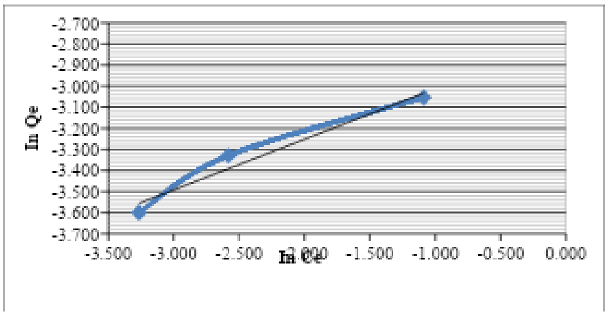

Figure 4. Freundlich Isotherm Calculation Results at a Stirring Speed of 200 rpm with a Contact Time of 60 Minutes

Based on ∫, graph of the Langmuir isotherm equation for the Kepok banana peel adsorbent at a stirring speed of 200 rpm with a contact time of 60 minutes, the linear equation y = 0.6635x + 19.178 with R^2 = 1,000 is obtained. Based on this linear equation, the adsorption capacity (Qm) is 0.0521 mg/g and the Langmuir constant (KL) is 28.9017 L/mg. The Langmuir equation provides information about the maximum adsorption capacity, taking into account the interactions between solute molecules on the surface of the adsorbent (Alifaturrahma & Hendriyanto, 2018).

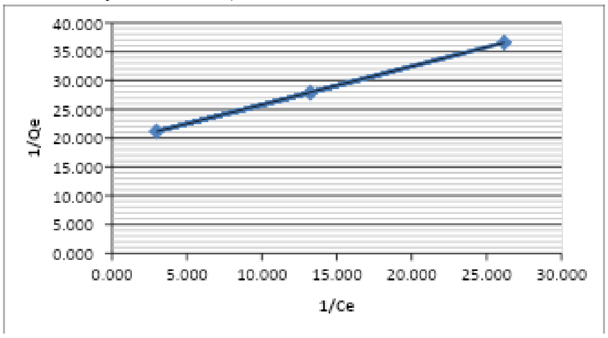

Figure 5. Langmuir Isotherm Calculation Results at a Stirring Speed of 200 rpm with a Contact Time of 60 Minutes

The Langmuir equation is 1.0000 while the Freundlich equation is 0.9581. Therefore, the adsorption isotherm that is more suitable for a stirring speed of 200 rpm is the Langmuir Isotherm. Langmuir occurs chemically, so the bond that occurs is very strong, and it is assumed that the adsorbate sticks to a layer (monolayer) on the surface of the adsorbent with the same active site (homogeneous) (Cundari et al., 2019; Molina-Calderón et al., 2022).

The study concludes that Kepok banana peels are highly effective as an adsorbent for reducing iron (Fe) levels in laboratory wastewater. The optimum conditions for Fe removal were achieved with an adsorbent weight of 4 grams and a stirring speed of 200 rpm, resulting in a removal efficiency of 98.28%. The initial concentration of Fe in the wastewater was 2.2259 mg/L, which was reduced to a final concentration of 0.0382 mg/L under these conditions. This significant reduction demonstrates the potential of Kepok banana peels as a sustainable and economical solution for treating wastewater contaminated with heavy metals. The adsorption process was found to follow the Langmuir isotherm model, indicating that the adsorption occurred on a homogeneous surface with monolayer coverage of Fe ions on the adsorbent. The presence of functional groups such as –OH, aliphatic CH, C=C alkene, and CO in the adsorbent, confirmed by FTIR analysis, played a crucial role in the adsorption process. This study highlights the potential application of Kepok banana peels as an eco-friendly adsorbent for environmental management, particularly in reducing Fe contamination in wastewater.

Conclusion

This study demonstrates that Kepok banana peels are highly effective as a low-cost and eco-friendly adsorbent for removing iron (Fe) from laboratory wastewater. The optimal adsorption conditions were achieved using 4 grams of adsorbent and a stirring speed of 200 rpm, resulting in a maximum Fe removal efficiency of 98.28%. Under these conditions, the initial Fe concentration of 2.2259 mg/L was reduced to 0.0382 mg/L.

The adsorption process followed the Langmuir isotherm model, indicating monolayer adsorption on a homogeneous surface with strong chemical interactions. FTIR analysis confirmed the presence of functional groups such as –OH, aliphatic CH, C=C alkene, and carbonyl (C=O), all of which contributed significantly to the adsorption process.

These findings support the potential of utilizing agricultural waste, particularly Kepok banana peels, as a sustainable solution for heavy metal removal in water treatment applications. Further research can explore its application on a larger scale or in combination with other

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treatment technologies to enhance overall efficiency and versatility.

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