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Analysis of the Effectiveness of Compost-Based Activated Carbon for the Removal of Heavy Metals from Leachate at Piyungan Landfill

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ABSTRACT

Leachate from the Final Disposal Site (TPA) in Piyungan, Yogyakarta, is a significant source of potential heavy metal contamination. This represents a serious environmental issue as it can pose a threat to human health and ecosystems. Given its significant negative impact, this study aims to evaluate the efficiency of Compost-Based Activated Carbon (CBAC) as an environmentally friendly alternative solution for reducing heavy metal concentrations in leachate. CBAC is produced through a pyrolysis and chemical activation process using 32% HCl. The study tested the ability of CBAC to adsorb Cr, Cu, and Pb from leachate samples. The results indicate that CBAC exhibits significant adsorption capacity, with the highest removal efficiency recorded for copper (Cu), reaching 52.38% in 20 minutes. The removal efficiencies for chromium (Cr) and lead (Pb) were 17.8% and 12.09%, respectively, although at different optimal times. These differences in efficiency suggest that the characteristics of each heavy metal influence its interaction with CBAC. The findings demonstrate the potential of CBAC as an effective and sustainable alternative in waste management, particularly in reducing heavy metal pollution. This study makes a significant contribution to the development of more environmentally friendly and sustainable waste management technologies, offering an innovative solution to address heavy metal contamination issues at TPA Piyungan and similar sites.

1. Introduction

The volume of waste in the Special Region of Yogyakarta (DIY) has experienced a significant increase of 52.8%, based on national waste data. The volume of waste increased from 1,240 tons/day in 2021 to 1,894 tons/day in 2022. This increase raises serious concerns regarding waste management in DIY. This situation indicates that the current waste management system is inadequate to handle the continually increasing waste volume. The resulting impacts affect not only the cleanliness and aesthetics of the environment but also cause more serious environmental problems. One of the waste processing facilities in DIY is the Piyungan Landfill (TPA).

Piyungan Landfill faces a major issue, which is the increasing production of leachate. Leachate is the liquid formed from the decomposition process of waste and contains various hazardous substances, including heavy metals such as chromium (Cr), copper (Cu), and lead (Pb) (Fitri et al., 2021). Heavy metals are known to have toxic properties that can harm human health and the environment (Zhong et al., 2024). Long-term exposure to heavy metals can cause various health problems, including neurological disorders, organ damage, and even cancer (Pratiwi, 2020).

Effective and sustainable management to reduce heavy metal contamination in leachate is needed at Piyungan Landfill. One technology that can be applied is adsorption using compost-based activated carbon, which has a good ability to adsorb various contaminants, including heavy metals. This technology can be used as a method to reduce the concentration of heavy metals in leachate (Zarkasi et al., 2018). The use of compost-based activated carbon is not only an economical solution but also environmentally friendly. The process of producing compost-based activated carbon can utilize existing organic waste, thereby reducing the volume of waste that needs to be managed. Furthermore, this technology supports the principles of circular economy, where waste can be processed into valuable products.

As an adsorbent medium, compost can be sourced from local Reduce, Reuse, Recycle (3R) Waste Processing Facility (TPS3R), which are managed with the goal of reducing organic waste. This processing not only helps reduce waste volume but also provides economic and environmental benefits. According to the 2021 report from the Regional Environmental Agency, the management of organic waste through TPS3R has been carried out at 0.84 tons/day. The process of converting compost into activated carbon is carried out through pyrolysis at temperatures between 400°C-600°C. This process aims to convert compost into charcoal, which is then chemically activated using strong acid or alkaline solutions. This activation is crucial as it enhances the porosity and surface area of the activated carbon, thereby maximizing its adsorption capacity for heavy metals. The activated carbon produced from the pyrolysis process has a higher adsorption capacity compared to conventional activated carbon (Mishra et al., 2024).

2. Methods

2.1 Time and Location

The study was conducted over a period of six months, starting from the preparation phase on March 19, 2024, followed by the sampling of leachate at the Piyungan Landfill. The sampling process was carried out at the inlet unit of the Leachate Treatment Facility at Piyungan Landfill, Yogyakarta. Sample collection and preservation followed the Indonesian National Standard (SNI) 6989.59:2008 regarding wastewater sampling methods. The samples were taken using the grab sampling method with a long-handled scoop. The leachate sample can be shown in Figure 1.

Figure 1. Leachate sample from Leachate Treatment Facility at Piyungan Landfill

2.2 CBAC Preparation

The preparation of CBAC utilized the CCC method (char, chemical, cook). The compost used as the primary material for CBAC production was organic compost obtained from TPS3R. The organic compost from TPS3R was made from food waste and yard waste (such as leaves, twigs, etc.), which have a favorable C/N ratio for activation and the production of activated carbon (Iresha et al., 2016). The preparation of CBAC involved compost that had been sifted and roasted, followed by chemical activation. The compost was mixed with HCl solution as the activator. HCl, as a chemical activator, is hygroscopic and can reduce the moisture content of the resulting activated carbon. Activated carbon treated with HCl has a better iodine adsorption capacity, as HCl dissolves impurities, allowing more pores to form and maximize the adsorption process (Alfiany, Bahri & Nurakhirawati, 2013). After activation, the material was dried using an oven for 20 min.

2.3. Adsorption Process

In this study, the adsorption process was conducted in a batch model by adding 2500 mg of CBAC to 500 ml of leachate, mixed at 50 rpm for 0, 20, 60, and 100 minutes. The effectiveness of CBAC in removing heavy metals, including chromium (Cr), copper (Cu), and lead (Pb), which are common leachate contaminants, was evaluated by analyzing absorbance using Atomic Absorption Spectrophotometry (AAS). The tests followed Indonesian National Standards (SNI) 6989.17:2009 for chromium, SNI 6989.6:2009 for copper, and SNI 06-6989.8:2004 for lead measurement in water.

3. Results and discussion

3.1 Removal Efficiency

The use of CBAC as an adsorbent contributes to environmentally friendly waste management and provides recommendations for more sustainable leachate treatment. The adsorption method effectively reduces the concentration of heavy metals (Faris & Titah, 2024). The adsorption method was applied using CBAC from TPS3R, with a dose of 2500 mg CBAC and 500 ml of leachate in a single batch test, with the results shown in Table 1. CBAC demonstrated significant performance in removing heavy metals from wastewater, with removal efficiencies ranging from 12-52%, depending on the type of heavy metal adsorbed. Moreover, adsorption using CBAC demonstrated the highest removal efficiency for Cu, reaching 52.38%, as shown in Table 2. The optimum removal times for Cu, Cr, and Pb were 20, 100, and 60 min, respectively.

Table 1. Heavy Metal Adsorption Results Using CBAC

	Cu		Cr		Pb	
Stirring Time (min)	**Concentration (mg/L)**	**Removal Efficiency (%)**	**Concentration (mg/L)**	**Removal Efficiency (%)**	**Concentration (mg/L)**	**Removal Efficiency (%)**
0	0.021	0	0.309	0	0.1762	0
20	0.010	52.38	0.294	4.85	0.1942	-10.22
60	0.023	-9.52	0.273	11.65	0.1549	12.09
100	0.021	0	0.254	17.80	0.1885	-6.98

Table 2. Optimal removal efficiency

Adsorbent	Adsorbate	Time (min)	Removal Efficiency (%)
CBAC	Cu	20	52.38
CBAC	Cr	100	17.80
CBAC	Pb	60	12.09

The removal efficiency of Cu heavy metal using activated carbon adsorbents is influenced by the type of material, contact time, and activator used, as shown in Table 3. The highest removal efficiency was achieved by activated carbon derived from coconut shells with Na_2CO_3 as the activator. Coconut shells are a promising material for producing activated carbon with high adsorption capacity (Batdjedelik & Sumardiyono, 2024), while Na_2CO_3 enhances this capacity by significantly improving the adsorption performance (Safitri et al., 2024). Additionally, in this study, activated carbon with HCl as an activator and a contact time of 100 minutes was found to be less effective for Cr and Pb removal compared to activated carbons activated with H_2SO_4 and H_3PO_4. H_2SO_4 works by opening the carbon pores of commercial activated carbon through oxidation, thereby enhancing its adsorption capacity (Astuti & Maiza, 2019). In contrast, H_3PO_4, used in activated carbon derived from rubber shells, helps open and develop the pores formed during the carbonization process, thus improving metal removal efficiency (Meilianti, 2017). The comparisons of CBAC adsorption performance for Cr and Pb with other studies are presented in Tables 4 and 5, respectively.

Table 3. Comparison of CBAC adsorption performance for Cu with other studies

Adsorbent	Contact Time (min)	Activator	Removal Efficiency (%)	Reference
CBAC	20	HCl	52.38	This study
AC – haycarb	40	NaOH	34.18	Anggriani et al., (2021)
AC - Water hyacinth	80	HCl	42.89	Fadhilah et al., (2021)
AC - Merkus pine flowers	120	NaOH	54.45	Rizky & Silalahi (2022)

Adsorbent	Contact Time (min)	Activator	Removal Efficiency (%)	Reference
AC – Activated carbon	60	NaOH	98.33	Angraini et al., (2022)
AC - Water hyacinth	80	HCl	42.89	Fadhilah et al., (2021)
AC – Chicken bone	60	HCl	98	Amalia et al., (2017)
AC – Coconut shell	45	Na_2CO_3	100	Silaban (2018)

Table 4. Comparison of CBAC adsorption performance for Cr with other studies

Adsorbent	Contact Time (min)	Activator	Removal Efficiency (%)	Reference
CBAC	100	HCl	17.8	This study
AC - Sugarcane bagasse	15	NaCl	8	Nurhayati et al., (2018)
AC – Corn cob	60	HCl	23.05	Rengga et al., (2019)
AC – Commercial	90	H_2SO_4	99.37	Febrina et al., (2019)
AC – Coconut shell	60	Na_2CO_3	73.52	A'yunina et al., (2022)
AC - Rubber fruit shell	180	H_3PO_4	96.67	Zulfadhil & Iriany (2017)
AC – Banana Peel	60	NaOH	58	Shafirinia et al., (2016)
AC – Corn cob	55	NaOH	74.28	Rokhati et al., (2021)

Table 5. Comparison of CBAC adsorption performance for Pb with other studies

Adsorbent	Contact Time (min)	Activator	Removal Efficiency (%)	Reference
CBAC	60	HCl	12,09	This study
AC – Coconut shell	1	HCl	77,81	Verayana et al., (2018)
AC – Coconut shell	1	H_3PO_4	92,81	Verayana et al., (2018)
AC – Rice husk	60	HCl	98,80	Wardalia (2016)
AC – Rice husk	180	NaOH	73,4	Wardalia (2016)
AC - Chitosan and tea waste	1440	$ZnCl_2$	90,6	Suwazan & Nurhidayanti (2022)
AC - Water hyacinth	150	$ZnCl_2$	99,99	Andarista et al., (2023)
AC - Coconut shell	45	Na_2CO_3	98	Silaban (2018)

3.2 Adsorption Isotherm of CBAC for Cu Metal

In this study, the adsorption isotherm analysis was only conducted on CBAC for the adsorption of Cu metal. This is because the adsorption results for Cr and Pb showed negative values. The negative values are suspected to indicate the potential that CBAC could act as a contaminant in water. The adsorption isotherm for Cu metal using CBAC can be seen in Figure 2.

Based on Figure 2, it can be observed that the R^2 value for the Temkin isotherm is higher than that for the Langmuir and Freundlich isotherms. This result suggests that the adsorption of Cu metal by CBAC predominantly follows the Temkin isotherm type. According to the study by Said et al. (2018), when the adsorption process follows the Temkin isotherm, it can be explained that the interaction between the adsorbate and adsorbent is influenced by adsorption energy, which decreases linearly with an increase in surface coverage, along with significant intermolecular interactions. The Temkin model illustrates that the adsorbent surface is heterogeneous, where variations in physical and chemical properties affect the adsorption capacity.

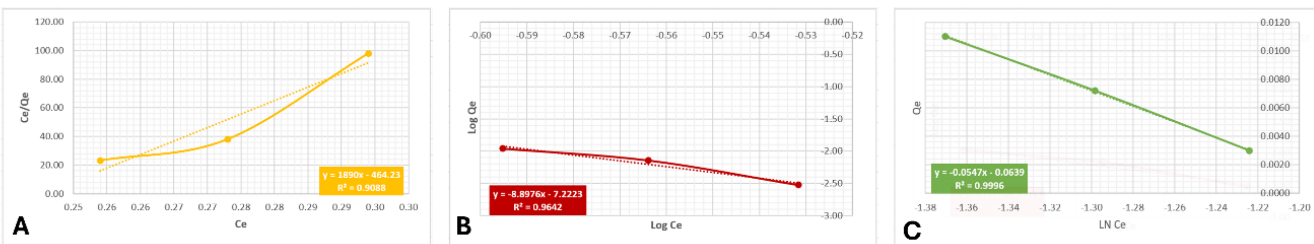

Figure 2. Adsorption isotherms of Cu: (a) Langmuir isotherm, (b) Freundlich isotherm, (c) Temkin isotherm.

4. Conclusions

This study successfully demonstrates that compost-based activated carbon (CBAC) is an effective solution for the removal of heavy metals from leachate at the Piyungan Integrated Waste Treatment Facility (TPA). Through pyrolysis and chemical activation methods, CBAC was able to enhance its adsorption capacity for heavy metals such as copper (Cu), chromium (Cr), and lead (Pb). The results show that CBAC can reduce the concentration of heavy metals with varying efficiencies, with copper showing the highest removal efficiency of 52.38% in 20 min, while chromium and lead exhibit lower but still significant removal efficiencies.

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