EFFECTIVENESS OF USING ACTIVATED CARBON TO REDUCE POLLUTANTS IN LEACHATE

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ABSTRAK

Pencemaran air lindi yang dihasilkan dari proses pelarutan material organik dan anorganik pada tempat pembuangan sampah terbuka merupakan masalah lingkungan yang serius. Air lindi mengandung berbagai polutan, seperti logam berat, senyawa organik, dan senyawa berbahaya lainnya yang dapat merusak kualitas air dan tanah jika tidak dikelola dengan baik. Penelitian ini bertujuan untuk menilai efektivitas karbon aktif dalam mengurangi polutan pada air lindi dan faktor-faktor yang mempengaruhi kinerja karbon aktif dalam pengolahan air lindi. Metode yang digunakan dalam penelitian ini adalah pengolahan air lindi menggunakan karbon aktif sebagai media adsorben. Pengujian dilakukan dengan variasi waktu kontak dan konsentrasi karbon aktif untuk mengetahui kondisi optimal dalam penyerapan polutan. Parameter kualitas air yang diuji meliputi COD, BOD, Fe dan Zn. Dari hasil penelitian didapatkan hasil bahwa karbon aktif sangat efektif dalam mengurangi kandungan polutan dalam air lindi hal ini dilihat dari hasil perhitungan efektivitas dimana didapatkan bahwa karbon aktif dapat menurunkan nilai COD sebesar 63,96%, BOD sebesar 44,89%, Fe sebesar 83,33%, dan Zn sebesar 83,33%.

Kata kunci: air lindi, efektivitas, karbon aktif

ABSTRACT

Leachate pollution resulting from dissolution process organic and inorganic materials in open landfills is a serious environmental problem. Leachate contains various pollutants, such as heavy metals, organic compounds, and hazardous compounds that can damage water and soil quality not managed properly. This study aims assess the effectiveness activated carbon in reducing pollutants in leachate and factors that affect the performance of activated carbon in leachate treatment. The method used in study is leachate treatment using activated carbon as an adsorbent medium. Testing was carried out with variations in contact time and activated carbon concentration to determine the optimal conditions for pollutant absorption. Water quality parameters tested included COD, BOD, Fe and Zn. The results of study showed that activated carbon is very effective in reducing pollutant content in leachate. This can be seen from results of the effectiveness calculation where it was found that activated carbon can reduce COD 63.96%, BOD 44.89%, Fe 83.33%, and Zn 83.33%.

Keywords: leachate, effectiveness, activated carbon.

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INTRODUCTION

Indonesia is one of the largest waste producers in the world, the amount of waste produced by Indonesia is 67.8 million tons with 37.3% of the waste source coming from household activities (Tilana & Widyastuti, 2024). Household waste, both solid and liquid, is obtained from daily activities originating from household activities (Simbolon et al., 2022). The solid waste produced is food waste, such as stale rice, fruit peels, and vegetables, while liquid waste includes leachate, rice washing water and clothes washing water (Ibrahim et al., 2023). High waste production if not handled properly and correctly can have a negative impact on the surrounding environment (Prisilla et al., 2024).

The impact of waste accumulation can cause waste to decompose which can release water called leachate waste (Haumahu et al., 2021). According to (Safria & Perdana, 2021) the emergence of leachate is due to the processing carried out at the TPA using a compacted anaerobic landfill system, namely a technique of piling up waste in a depression then filling it with soil until there are no air cavities, the layer is continued until the design height has been determined to form a layer 30-50 cm thick, this causes external water that enters the landfill to produce leachate output. Leachate is a liquid produced from water infiltration through waste piles at the final disposal site (TPA) (Anggriawan et al., 2019).

According to (Gemala & Ulfah, 2020) leachate, which is often also called landfill leachate, is a liquid produced from water infiltration into waste piles at the final disposal site (TPA). This leachate contains various pollutants, such as heavy metals, organic materials, toxic chemical compounds, and pathogenic microorganisms that can pollute the environment if not properly treated (Asiva Noor Rachmayani, 2015).

This water contains various toxic substances, including organic compounds, heavy metals, and pathogenic microorganisms that can pollute the surrounding environment (Nofiyanto et al., 2019). Leachate pollution, especially to groundwater sources, can cause ecosystem damage and public health problems (Yuningrat, 2015). Leachate contains hazardous substances, especially if it comes from waste mixed with B3 waste (Hazardous and Toxic Materials) (Nofiyanto et al., 2019). If not treated specifically, leachate can pollute wells/groundwater, river water, and even seawater and cause the death of marine biota (Simbolon et al., 2022).

Activated carbon has been widely known as an effective adsorbent in water treatment processes due to its ability to absorb various types of pollutants, including heavy metals, organic compounds, and other hazardous chemicals (Roni et al., 2021). With very small pores and a large surface area, activated carbon can trap pollutant molecules from leachate, making it a potential solution in wastewater treatment (Ali et al., 2020). Activated carbon has a large surface area and sufficient pores to adsorb various types of pollutants (Hadisoebroto et al., 2023).

The adsorption process using activated carbon is an effective method for reducing pollutant concentrations (Rahayu et al., 2023). Activated carbon has a porous structure and a very large surface area, enabling it to adsorb these pollutants through physical and chemical mechanisms (Zulaicha et al., 2025). Due to its hydrophobic properties, activated carbon can bind non-polar organic compounds, while functional groups on its surface can attract polar compounds and metal ions (Efiyanti et al., 2020). According to (Gemala & Ulfah, 2020) the use of activated carbon in wastewater treatment has been proven to reduce the concentration of pollutant parameters. The effectiveness of this reduction depends heavily on the characteristics of the activated carbon used, including pore size, surface area, and type of activation (Cipta et al., 2025).

Therefore, this study was conducted to examine the effectiveness of activated carbon in reducing leachate pollution, focusing on important parameters such as pollutant concentration, contact time, and pH. To solve the problems contained in the background of the problem, the formulation of the problem can be formulated as follows how effective is activated carbon in reducing pollutant content in leachate and what factors affect the performance of activated carbon in leachate treatment. Research on the effectiveness of using activated carbon for leachate treatment aims to assess the effectiveness of activated carbon in reducing pollutants in leachate and the factors that influence the performance of activated carbon in leachate treatment.

METHOD

This research is experimental using the adsorption method to test the ability of activated carbon to reduce pollutant content in leachate (Setiorini & Agusdin, 2018). Experimental research is research conducted with a scientific approach using two variables (Anggriawan et al., 2019). Where the first variable is testing leachate without treatment using activated carbon while the second variable is testing water with treatment using activated carbon (Rahmi & Sajidah, 2017). The parameters to be tested are BOD, COD, Fe, and Zn parameters.

Research Tools And Materials

In this research, the primary tools employed were the Adsorption Pond as the primary adsorption site. Measurements and sampling were conducted using Pyrex beaker glasses and measuring cups, accompanied by volumetric or dropper pipettes (also Pyrex). Material weighing was performed using an electronic analytical balance, Want FA2204HM. Metal content and other parameters were measured using a Faithful AAS Spectrophotometer, a Hitachi UV-Vis Spectrophotometer, and a Lutron DO-5510 Do Meter. Stirring and heating were accomplished using a Thermo Cimarec hot plate and magnetic stirrer, while filter paper served as supporting laboratory equipment. Surface and structural analyses were conducted using a FEI Inspect-S50 Scanning Electron Microscope, with sample coating performed via a Sputter Coating Coater. Sample preparation involved mortar and pestle and anti-magnetic tweezers, while drying was achieved using a vacuum desiccator and an oven from Faithful. Glass slides or SEM holders provided support for SEM observations. The materials utilized were activated carbon as the adsorbent, leachate as the research sample, and distilled water as the solvent. Analytical reagents included COD reagent, BOD reagent, HCl, and HNO_3, while 1,10-Phenanthroline and Dithizone served as color reagents for Fe and Zn analyses.

Study Location

The research location was carried out at the Banjarsari TPA located in Banjarsari Village, Trucuk District, Bojonegoro Regency. The research time was carried out from December 2024. Leachate adsorption using activated carbon was carried out with different contact time conditions. Leachate as a sample was taken directly from the Banjarsari TPA. The adsorption process was carried out at contact times of 10, 20, 30, 40, 50 minutes. In the study, 100 ml of leachate samples were taken and adsorption was carried out with the addition of 0.4 grams of activated carbon.

Figure 1. Leachate Sampling Location

Data Analysis

Data that must be collected before and after treatment using activated carbon, include:

- Pollutant content in leachate: Can include parameters such as BOD, COD, Fe, and Zn parameters.
- Concentration of activated carbon: The concentration or dose of activated carbon used is 0.4 grams.
- Contact time or the length of time activated carbon interacts with leachate, namely 10, 20, 30, 40, 50 minutes
- Leachate pH: pH before and after treatment.
- Leachate volume: 100 ml of leachate used in the experiment.
- Effectiveness Calculation: For each pollutant parameter, you can calculate its effectiveness using the following formula:

$$E\ (\%) = \frac{A - B}{A} \text{ x } 100\% \quad (1)$$

Where:

E = Reduction Effectiveness (%)

A = Initial Concentration

B = Final Concentration

RESULTS AND DISCUSSION

The leachate used was analyzed first to determine the decrease and difference after being added with activated carbon. The analysis was carried out based on COD, BOD, Fe and Zn metal parameters. The COD content is an indication of the amount of oxygen needed by the oxidizer to decompose insoluble substances in 1 L of leachate (Purwitasari et al., 2022). This shows the amount of insoluble substances in the leachate. The COD content in leachate is 265 mg/L while the quality standard is 300 mg/L. The higher the COD value, the more dissolved oxygen is needed for the chemical process, as a result it can reduce the availability of dissolved oxygen for the life of aquatic organisms (Dewi et al., 2021).

BOD content is an indication of the amount of oxygen needed by microorganisms to decompose organic matter in 1 L of leachate (Nenohai et al., 2023). The BOD content in leachate is 81.3 mg/L while the quality standard is 150 mg/L. Based on COD and BOD parameters, leachate is no longer suitable for disposal into the environment without prior treatment.

Based on the analysis of Fe and Zn, it was found that the dissolved metal content was still below the quality standard, which was 0.03 mg/L, while the quality standard was 5 mg/L. Sampling was carried out during the rainy season, resulting in low levels of dissolved metal. However, the dissolved metals present indicate that there has been the formation of metal solutions resulting from the continuous decomposition of waste (Rohmah & Redjeki, 2018).

The effectiveness of the absorption of pollutant concentrations in the Banjarsari TPA leachate as a whole is shown in Table 1. The final concentration of pollutants for the COD, BOD, Fe and Zn parameters all reached the quality standard with fairly high absorption effectiveness. The parameters to be tested are COD, BOD, Fe and Zn.

Table 1. Effectiveness of Absorption of Pollutant Concentrations in Leachate at the Bajarsari TPA

Number	Parameter	Leachate Test Results	Leachate Test Results (Addition of Activated Carbon)	Effectiveness (%)	Quality Standards
1	COD	265 mg/L	95,5 mg/L	63,96 %	300 mg/L
2	BOD	81,3 mg/L	44,8 mg/L	44,89 %	150 mg/L
3	Fe	0,005 mg/L	0,003 mg/L	83,33 %	5 mg/l
4	Zn	0,005 mg/L	0,003 mg/L	83,33 %	5 mg/L

Caption: Test Results 2025
Leachate Water Quality Standards: Regulation of the Minister of Environment No. 5 of 2014 Concerning Waste Water Quality Standards

Leachate adsorption using activated carbon was carried out with different contact time conditions (Efiyanti et al., 2020). Leachate as a sample was taken directly from the Banjarsari TPA. The adsorption process was carried out at contact times of 10, 20, 30, 40, 50 minutes. In this study, 100 mL of leachate was adsorbed with the addition of 0,4 grams of activated carbon. The table above shows the level of effectiveness (%) of reducing pollutant concentration in leachate after the addition of activated carbon for four main parameters, namely COD, BOD, Fe, and Zn.

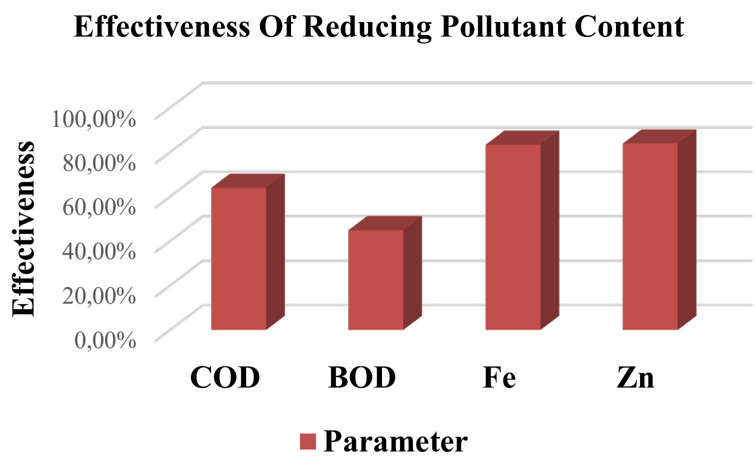

Figure 2. Effectiveness of Reducing Pollutant Content in Leachate

Figure 2 shows that the COD parameter has an effectiveness value of 63.96%. This indicates that the effectiveness of activated carbon in reducing Chemical Oxygen Demand (COD) is quite good, reaching almost 64%. This decrease indicates that activated carbon is able to absorb most of the complex organic compounds in leachate. For the BOD parameter, the lowest effectiveness is shown in the Biochemical Oxygen Demand (BOD) parameter, which is only 44.89%. This can occur because some of the compounds that cause BOD are biodegradable compounds that are not fully absorbed by activated carbon, and are more effectively processed through biological processes. While the Fe and Zu parameters show the highest effectiveness, which is 83.33%. This shows that activated carbon is very effective in absorbing heavy metals such as iron (Fe) and zinc (Zn). This is in line with the properties of activated carbon which has a large surface area and high affinity for metal ions.

Based on the results of the effectiveness test above, it was found that the use of activated carbon from coconut shells can reduce Fe and Zn content because the activated carbon contains lignin, cellulose, and hemicellulose which are able to absorb metal content (Dewi et al., 2021). In leachate treatment, the performance of activated carbon is influenced by various factors that can affect its effectiveness in absorbing pollutants (Nenohai et al., 2023).

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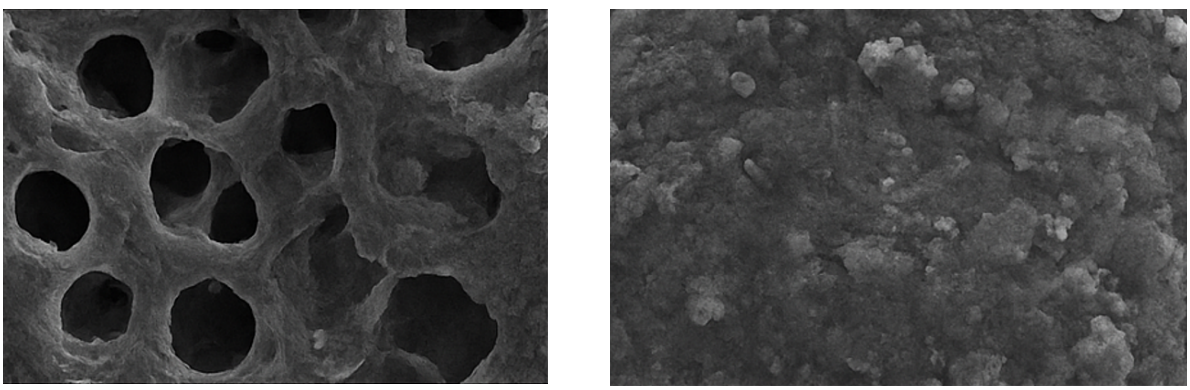
Characterization of activated carbon can be seen by SEM (Scanning Electron Microscopy) where the results of the study showed that before use the surface of activated carbon appeared to have an open and unfilled pore structure, rough and uneven texture, many micro pores and macro pores. After activated carbon was used for leachate absorption, the surface appeared denser and the pores were closed, there was foreign material or sediment covering the surface, this indicated that pollutants from leachate had been absorbed, and its morphology became more irregular, this indicated that there had been an interaction between activated carbon and pollutants. Figure 3 shows that activated carbon has a large surface area, which is very effective in absorbing dissolved substances from leachate.



Before Adsorption **After Adsorption**

Figure 3. Condition of activated carbon before and after leachate adsorption based on SEM (Scanning Electron Microscopy)

The following are the main factors that affect the performance of activated carbon in leachate treatment:

1. Physical and Chemical Properties of Activated Carbon
   - Particle Size: Activated carbon with smaller particle size has a larger surface area, thus increasing the adsorption capacity.
   - Pore Structure: Activated carbon with micro and meso pores is more effective in adsorbing small and medium-sized molecules found in leachate.
   - Surface Area: The larger the surface area of activated carbon, the greater its capacity to adsorb contaminants.

- Surface Chemical Properties: Functional groups on the surface of activated carbon, such as hydroxyl, carbonyl, and carboxyl groups, can interact with contaminants and affect the effectiveness of adsorption.

2. Pollutant Concentration

   The higher the concentration of pollutants in leachate, the greater the adsorption capacity of activated carbon required. At very high pollutant concentrations, activated carbon can reach saturation point more quickly.

3. Leachate pH

   The pH of leachate affects the chemical properties of activated carbon and pollutant speciation. For example, activated carbon is more effective at adsorbing heavy metals in acidic conditions (low pH), while some organic compounds may be better adsorbed at higher pH.

4. Contact Time

   The longer the contact time between leachate and activated carbon, the greater the chance of adsorption occurring. However, there is a certain limit where increasing contact time no longer significantly increases the adsorption capacity.

5. Temperature

   Temperature can affect the rate of diffusion of pollutants into the pores of activated carbon. In general, higher temperatures increase the kinetics of adsorption, but at too high temperatures, the adsorption capacity can decrease due to desorption of pollutants from activated carbon.

6. Presence of Interfering Substances (Adsorption Competition)

   Leachate often contains various types of pollutants, including organic and inorganic substances. These substances can compete for adsorption by activated carbon, thereby reducing the adsorption capacity for certain compounds.

7. Concentration of Activated Carbon

   The amount of activated carbon used also has an effect. The more activated carbon used, the greater the adsorption capacity, but it is necessary to pay attention to cost efficiency and excessive use which is not always comparable to increased effectiveness.

8. Nature and Type of Pollutants

   The type of pollutant in leachate, such as heavy metals, organic compounds, or inorganic compounds, will affect the effectiveness of activated carbon. For example, activated carbon is very effective for absorbing large organic compounds, but may be less effective for some heavy metals.

CONCLUSION

The results of the study can be concluded that activated carbon is very effective in reducing pollutant levels in leachate, this can be seen from the results of the effectiveness calculation where it was found that activated carbon can reduce COD values by 63.96%, BOD by 44.89%, Fe by 83.33%, and Zn by 83.33%. With the effectiveness results above, the adsorption process was carried out at contact times of 10, 20, 30, 40, 50 minutes where 100 mL of leachate was needed and adsorption was carried out with the addition of 0.4 grams of activated carbon. From the results of the research carried out, activated carbon has several limitations, including that activated carbon is not effective against all types of contaminants, this can be seen from the results of the effectiveness calculation on the BOD parameter, which is 44.89%. In field applications (for example in landfills), activated carbon is susceptible to mixing with mud or suspended solids, so that it can reduce effectiveness and requires the right filtration equipment to work optimally.

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