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Research Paper

Adsorption of Cadmium Metal in Liquid Waste Using Adsorbent Product of Pyrolysis of Teak Wood Biomass Waste

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Abstract: Liquid waste containing cadmium metal has the potential to be dangerous if not handled properly. One effort to reduce the concentration of cadmium metal in liquid waste is by the adsorption method. Teak sawdust can be processed into charcoal using pyrolysis techniques. Furthermore, charcoal can be activated to be used as a bio-adsorbent in liquid waste containing cadmium. The purpose of this study was to determine the mass ratio and optimum contact time of teak sawdust bio-adsorbent in reducing the concentration of cadmium metal in liquid waste in the nickel industry. The study was conducted by pyrolyzing teak sawdust waste. The resulting charcoal was then activated. Furthermore, 50 mL of liquid waste containing cadmium was mixed with bio-adsorbent and then adsorbed in time variations of 30, 60, 90, 120, 150, 180 minutes with the ratio of active mass to liquid analysis wastewater respectively 0.5g: 50mL, 1g: 50mL, 1.5g: 50mL, 2g: 50mL, and 2.5g: 50mL. After that, the Analysis wastewater was filtered with filter paper and the filtrate was analyzed for cadmium metal content using Atomic Absorption Spectrophotometry (AAS). The results showed that at a mass ratio of bio-adsorbent and cadmium liquid waste of 200mg: 50 mL at 150 minutes, the value of the absorbed Cadmium metal content was 0.1845 mg/L or 98.8% of cadmium was absorbed on the bio-adsorbent. Bio-adsorbent from teak sawdust waste has the potential to be used to reduce the levels of Cadmium metal in liquid waste.

Keywords: Bio-adsorption; Teak Wood Activated Charcoal; Cadmium Liquid Waste.

1. Introduction

Waste is waste whose presence at a certain time and place is not desired by the environment because it has no economic value. This waste can be in the form of liquid waste, solid waste, or gas waste. Likewise, in the process of analysis activities in the laboratory, it certainly has the potential to produce residual analysis activities in the form of waste that can have a negative impact on the environment and living things around the laboratory. The waste produced is potentially hazardous or toxic which can pollute or damage the environment either directly or indirectly [1].

The remaining results of laboratory activities that are not collected are also disposed of during the process of washing the container through the drain. Although the amount is not much, because it is continuous, of course this will have the potential to cause various negative impacts on the environment [2]. Given the large potential risk that will be caused by hazardous and toxic waste (B3) used in laboratory activities, it is seen as an urgency to make efforts to minimize the potential negative impacts [3].

In its implementation, proper waste management certainly requires knowledge of the characteristics of the waste. The characteristics of waste are highly dependent on the source of waste and the activities of the waste producer, and are influenced by particle size, dynamic nature, wide distribution and long-term impact[4]. The type of material used can also change from time to time depending on the activities in the laboratory. After waste identification through preliminary analysis, parameter data was obtained that exceeded the waste quality standard value according to the regulation of the Minister of Environment of the Republic of Indonesia Number 5 of 2022, namely Cadmium (Cd) with a concentration of 29.4250 mg/L from the required quality standard value of 0.1 mg/L. Efforts to reduce the increasing heavy metal pollution in the environment are directed at the use of materials that are easily degraded [5]. One method that can be used is the adsorption method. Adsorption is a separation process in which certain components of a fluid phase move to the surface of a solid substance that absorbs. The absorbed material is called the adsorbate and the material that functions as an absorbent is called the adsorbent [6]. The adsorption method has several advantages, including a relatively simple process, relatively high effectiveness and efficiency, and does not provide side effects in the form of toxic substances [7].

Adsorbent is a substance that absorbs other substances (either solid, liquid, or gas) in the adsorption process. According to Brady, (1999) [8], adsorbents are generally specific, only absorbing certain substances. In choosing the type of adsorbent in the adsorption process, it is adjusted to the nature and condition of the substance to be adsorbed.

The smaller the pores of the adsorbent, the larger the surface area [9]. Thus the adsorption rate increases. The most widely used adsorbent to absorb substances in solution is charcoal (activated carbon). Each adsorbent particle is surrounded by molecules that are absorbed because of attractive interactions. Absorption is selective, only dissolved substances or solvents are absorbed [10]

Bio-adsorbent resulting from the pyrolysis of teak sawdust waste (tectona grandis) is charcoal that is processed in such a way that it has high absorption/adsorption capacity for materials in solution, including wastewater. Activated carbon is widely used as an adsorbent and generally has a large capacity to adsorb organic molecules. Bio-adsorbent or activated carbon is a carbon that has good absorption capacity for anions, cations and molecules in the form of organic and inorganic compounds, solutions or gases [11]. Sawdust contains lignin, cellulose and hemicellulose so that sawdust has the potential to absorb metal ions. The OH group in cellulose and hemicellulose causes polar properties in the adsorbent. Thus, cellulose and hemicellulose are stronger in absorbing polar substances than non-polar ones. One type of wood that contains high cellulose is teak wood with a cellulose content of 47.5%.

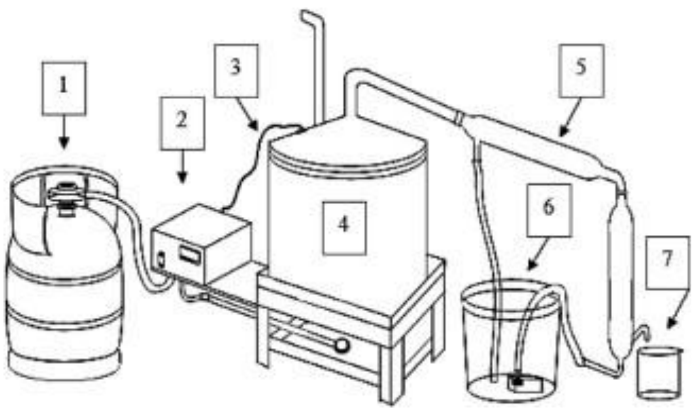
Various factors such as surface area, pore size, number of pores and the presence of functional groups on the surface affect the adsorption capacity. This leads to the modification of the adsorbent so that the adsorbent has physical and chemical properties to increase the ability to remove metal ions from the solution [12]. Activation aims to modify the surface of the adsorbent. Activation can be done by physical, chemical or physical-chemical methods. Therefore, it is necessary to conduct a study on the Cd adsorption process with adsorbents of variations in aquadest washing and chemical activation. This study aims to determine the optimum time needed to reduce the concentration of Cadmium contained in liquid waste using adsorbents from biomass waste pyrolysis [13]. The potential for biomass utilization in Indonesia is quite large, especially in the use of biomass waste which has not been maximized. When biomass waste such as sawdust is utilized directly, it can cause a number of problems such as low combustion efficiency, low density, and high pollutant emissions [14].

Previously, there have been several related studies from our research variables, namely: Analysis of the effect of rice husk bio-adsorbent dose on the adsorption of Cadmium (Cd) metal from Sasirangan waste [15], the results of the study showed that after activation, the higher the dose of bio-adsorbent, the smaller the ability of rice husk bio-adsorbent to adsorb Cd metal because the more the dose of bio-adsorbent used, the solution will experience saturation point [16]. In another study discussing the adsorption of Cd metal in laboratory liquid waste using bio-adsorbent from matoa fruit skin [17] the results of the study showed that adsorption was carried out at pH 9, contact time 40 minutes, and adsorbent mass 0.25 grams. Liquid waste contains Cd metal ions of 50.39 mg / L. After adsorption, Cd metal ions were detected at 19.17 mg / L, so that the adsorbed Cd metal ions were 31.22 mg / L. The adsorption efficiency is 61.96% and the adsorption capacity is 6,244 mg/g. In another study that discussed the determination of the optimum ratio of halal bio-adsorbent from coconut stem sawdust pyrolysis products in VCO clarification [14] where the results of the study showed that the optimum ratio of bio-adsorbent to VCO volume was 2 g/mL which provided a level of clarity (turbidity) of 1.15 NTU based on VCO characteristics, VCO filtered with bio-adsorbent has met SNI and international standards compared to VCO circulating on the market [11].

2. Research and Methodology

2.1 Materials

The tools used in the study were a set of pyrolysis tools, ovens and other auxiliary tools commonly used in the relevant laboratory. The materials used were samples of laboratory liquid waste before being processed by the Nickel Industry WWTP which were identified as containing Cadmium waste, samples of 1000 ppm Cadmium standard solution and teak sawdust and other auxiliary materials commonly used in the relevant laboratory.



Description:

1. LPG Cylinder
2. Temperature Indicator
3. Thermocouple
4. Pyrolysis Reactor
5. Condenser
6. Condensation Container
7. Liquid Smoke Container

Figure 1. Pyrolysis Equipment Series

2.2 Experiments

The sampling tool is made of materials that do not affect the nature of the sample. The tool used for wastewater sampling is a water sampler. The number of containers prepared must always be more than what is needed, for quality assurance, quality control and reserves. The volume of samples taken for field and laboratory examination purposes depends on the type of examination required. For this study we took a sample volume of ± 5 liters.

2.3 Sample Preparation

Teak sawdust is dried directly under sunlight for 3 (three) days, until the water content is below 15%, then prepare approximately 10 kg of bio-adsorbent for pyrolysis.

2.4 Bio-adsorbent Manufacturing

The prepared teak sawdust is dried under the hot sun, starting at 09.00-16.00 WITA for 3 consecutive days. The dry teak sawdust is charcoaled using a pyrolysis tool for 1 hour at a temperature of 300°C. The resulting charcoal is then ground. Furthermore, sieving is carried out with a size of 200 mesh. A sample of charcoal without activator is obtained.

2.5 Determination of Optimum Contact Time of Bio-adsorbent

Bio-adsorbent weighing 1 gram was contacted into a 50ml wastewater solution which was put into an Erlenmeyer. The mixture was stirred using a magnetic stirrer, carried out with time variations of 30, 60, 90, 120, 150, 180 minutes. After that the mixture was filtered using Whatman filter paper no. 42, then the solution/filtrate obtained was analyzed using an Atomic Absorption Spectrophotometer (AAS).

2.6 Test of the Effect of Bio-adsorbent Mass Comparison on Wastewater

The weighed bio-adsorbent with various mass ratios of bio-adsorbent to wastewater (0.5g:50mL, 1g:50mL, 1.5g:50mL, 2g:50mL, and 2.5g:50mL) was mixed. Then the mixture was stirred using a magnetic stirrer at the optimum time of the bio-adsorbent. After that, the mixture was filtered using Whatman filter paper, then the solution/filtrate obtained was analyzed using an Atomic Absorption Spectrophotometer (AAS).

2.7 Results Analysis

Analysis of Cd (Cadmium) levels in wastewater and Cd (Cadmium) levels after contact with bio-adsorbent was carried out using Atomic Absorption Spectrophotometer (AAS) analysis.

3. Results and Discussion

Determination of water content is carried out to determine the amount of water content in teak sawdust and activated carbon. High or low water content indicates the amount of water that covers the pores of activated carbon. Adsorption will be optimal if the water content is low. This is because the lower the water content, the more adsorbates can occupy the pores [18]. In this case, the water content of teak wood waste was tested using the SNI method. 06-3730-1995 of 11%.

Determination of metal residue levels is carried out to determine the amount of cadmium (Cd) metal contained in the liquid waste of the Nickel Industry. Before testing the metal content, a series of standard solutions are first prepared. The standard solution is extracted from the stock solution, in this case 0.5257 grams of Cd $(NO_3)_2$ is weighed then dissolved in distilled water, placed in a 250 mL measuring flask. and the volume of the solution is adjusted to distilled water. The main solution is 1000 ppm Cd This solution is diluted in preparing a standard series solution using a standard series and adsorption.

Table 1. Initial Test Results for Cadmium (Cd) Metal

Waste Sample Data	Cadmium (Cd)
Abs	0,1963
Ppm	29,4250

The observation results showed that the concentration of heavy metal cadmium (Cd) in the laboratory waste of the Nickel Industry reached 29.4250 mg/L, far exceeding the threshold set by the Indonesian National Standard (SNI 6989.16:2009), which is 0.1 mg/L. The high levels of cadmium indicate that waste management has not met the required standards, thus potentially causing negative impacts on the environment and health.

Cadmium is a toxic heavy metal that can accumulate in the food chain and cause damage to aquatic ecosystems if released without adequate treatment. In humans, exposure to cadmium can trigger serious health problems such as kidney damage, liver dysfunction, and other chronic diseases [19]. In addition, non-compliance with this threshold also violates national regulations, such as those stipulated in Government Regulation Number 22 of 2021 concerning Environmental Management, which requires all industrial activities, including laboratories, to comply with strict waste quality standards. To address this problem, the Nickel Industry needs to optimize waste treatment technologies, such as adsorption or chemical precipitation methods, which have proven effective in reducing heavy metal concentrations [20]. In addition, companies need to conduct regular audits of laboratory activities, provide waste management training to employees, and routinely monitor waste quality to ensure compliance with applicable regulations. With these steps, the Nickel Industry can minimize the risk of environmental pollution, improve operational sustainability, and fulfill social and environmental responsibilities.

Table 2. Final Test Results of Cadmium (Cd) Metal Based on Contact Time

Mass (mg)	Time (min)	Abs	Ppm
50 mg	0	0.1963	29,4250
50 mg	30	0.0820	12,6972
50 mg	60	0.0119	2,5378
50 mg	90	0.0107	0.9860
50 mg	120	0.0096	0.5046
50 mg	150	0.0087	0.3672
50 mg	180	0.0080	0.3321

Based on Table 2, it can be concluded that the best time for waste absorption occurs at the 150th minute. This is indicated by the significant decrease in waste concentration at that minute, where the results are not much different from the absorption at the 180th minute. Thus, it can be assumed that the absorption process reaches optimal conditions at the 150th minute, so that additional time up to the 180th minute does not provide a significant increase in absorption effectiveness.

Optimal absorption at the 150th minute indicates that the adsorption system has reached saturation point or is almost approaching equilibrium between the adsorbent and waste at that time. This is relevant to the principle of adsorption kinetics, where initial absorption usually occurs rapidly due to the large number of active sites on the available adsorbent surface, then slows down when approaching saturation conditions [21].

To further support these results and ensure the effectiveness of the absorption process, the next step planned is to conduct trials with variations in adsorbent mass. This study aims to determine the effect of the amount of adsorbent on the capacity and efficiency of waste absorption. By changing the mass of the adsorbent, it is expected to obtain more detailed data on the relationship between adsorbent capacity and absorption time, as well as determine the optimal mass that can be used efficiently without wasting material. This step is also important to identify the best operating conditions that can be applied on a large or industrial scale. In addition, this further testing can provide deeper insight into the potential use of more economical or environmentally friendly adsorbent materials for waste management, thereby supporting the reduction of environmental impacts generated by industrial activities.

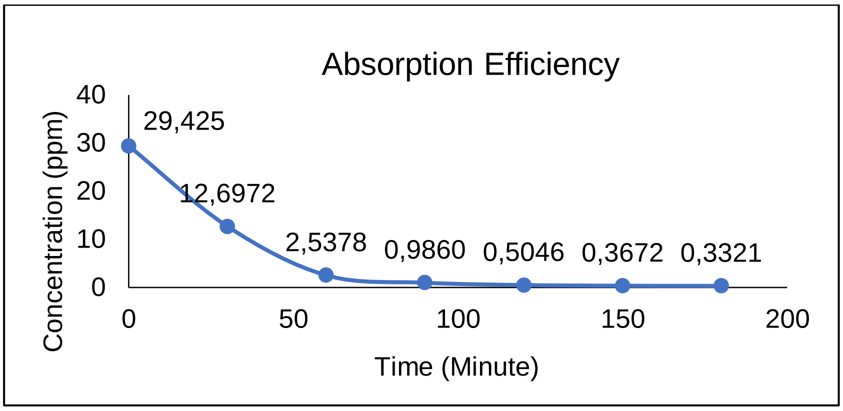


Figure 2. Absorption Efficiency

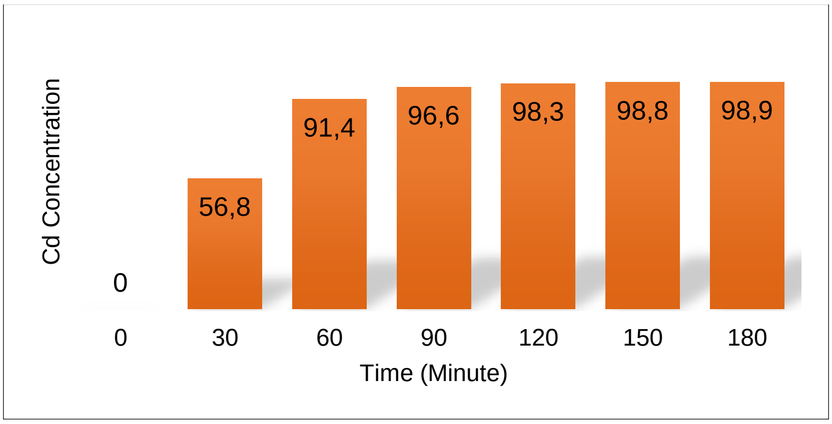


Figure 3. Percentage of Cadmium absorbed

Based on the graph above, it can be concluded that the best time to absorb cadmium residue is at the 150th minute. At this time, the concentration of cadmium residue reaches the lowest value, which is 0.3672 ppm. This indicates that the level of adsorption by the adsorbent material reaches optimal conditions. The decrease in the concentration of metal residue indicates the success of the adsorption process in reducing cadmium levels in waste solutions, as explained by previous research [22], which shows that contact time affects the efficiency of heavy metal absorption [23].

This phenomenon can be explained by the principle of adsorption kinetics, where longer contact times provide a greater opportunity for adsorbent particles to come into contact with metal ions. During this process, metal ions bind to pores or active sites on the surface of the bio-adsorbent. As explained by Low (1995), the longer the contact time, the more metal ions can be adsorbed, until finally a saturated condition is reached when all active sites on the adsorbent have been filled.

The significant decrease in cadmium concentration up to the 150th minute indicates that at that time the optimal absorption process has occurred. After this time, increasing the contact duration did not have a significant effect on the adsorption efficiency, which could be due to the limited number of active sites remaining on the adsorbent surface [24].

These results support the importance of selecting the right contact time in the adsorption process to improve waste treatment efficiency. Further research can be conducted with variations in other parameters, such as adsorbent mass, particle size, or initial metal concentration, to obtain more optimal operational conditions. Thus, these results can be a reference in designing a more effective and efficient adsorption-based waste treatment system.

This discussion is in line with previous research [4] which emphasized that contact time affects the efficiency of heavy metal absorption and stated that increasing contact time increases adsorption until it reaches saturation point. In addition, these findings are consistent with Utami & Mali (2023) [25],which explain that after a certain time, adsorption efficiency no longer increases due to limited active sites on the adsorbent. Thus, this study confirms that selecting the optimal contact time is very important in the adsorption process for waste treatment, and opens up opportunities for further research with other variables to increase the efficiency of the adsorption system.

Table 3. Final Test Results of Cadmium Metal Based on Mass Variable

Optimum Time (minute)	Mass (mg)	Abs	Concentration (ppm)
150	0	0,1963	29,4250
150	50	0.1421	2.1515
150	100	0.0268	0.3851
150	150	0.0187	0.2611
150	200	0.0137	0.1845
150	250	0.0013	-0.0055

From Table 3 above, it can be said that the best mass variation for Cadmium waste absorption is at 200 mg, with an absorption rate of up to 98.8%.

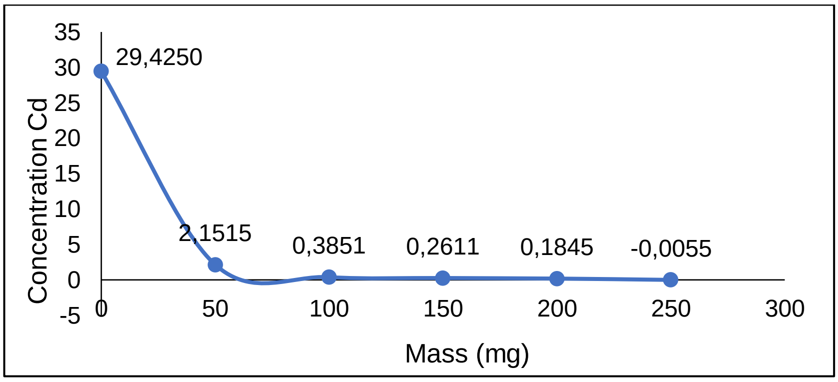


Figure 4. Comparison graph of mass to cadmium waste absorption

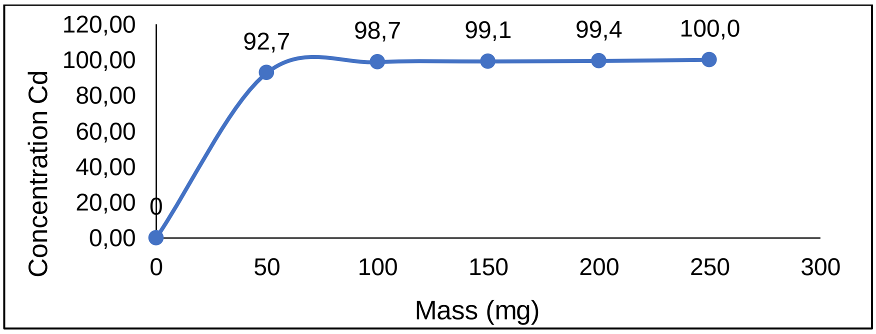


Figure 5. Percentage of Cadmium Absorption Based on Mass Variation

Based on the graph above, it can be seen that the smallest residual absorption concentration occurs at an adsorbent weight of 200 mg with the best contact time of 150 minutes, resulting in a final concentration of 0.1845 ppm. These data indicate that the addition of adsorbent mass directly contributes to an increase in the absorption capacity of metal ions in waste. The more adsorbent used, the greater the number of empty pores available to absorb metal ions, so that the level of absorption efficiency increases.

This process is in accordance with the principle of adsorption, where the pores of the adsorbent act as active sites to bind metal ions. When the amount of adsorbent increases, the total surface area available for contact with the waste also increases, allowing more metal ions to be adsorbed. This phenomenon is in line with the research [26], which states that the absorption capacity of the adsorbent will increase until it reaches a saturation point where all active sites are filled.

The decrease in residue concentration to 0.1845 ppm at 200 mg adsorbent weight and 150 min time indicates that this combination is close to the optimal conditions for cadmium waste treatment. However, it is important to note that excessive increase in the amount of adsorbent can reduce the efficiency of the process economically, because the use of disproportionate materials does not provide significant benefits to the absorption capacity [6]. The data in this discussion shows that increasing the mass of adsorbent to 200 mg increases the efficiency of metal ion absorption, with the residue concentration reaching 0.1845 ppm at a contact time of 150 min. This result is consistent with the study [15], which stated that the absorption capacity increases with the increase in the surface area of the adsorbent to the saturation point. In addition, this finding supports the study, which emphasized that excessive use of adsorbent does not always increase efficiency economically. Thus, the results of this study confirm that there is an optimal limit in the amount of adsorbent used for adsorption-based waste treatment.

4. Conclusion

The best absorption time to absorb Cadmium metal waste is 150 minutes. The best mass ratio for Cadmium metal absorption is at a mass variation of 200mg with an effectiveness of 98.8%. Bio-adsorbent from pyrolysis of teak sawdust waste used as an adsorbent in this study was able to reduce the concentration of heavy metal waste Cadmium (Cd) by 98.8% from 29.4250 ppm to 0.1845 ppm.

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