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Neutralizing Acid Mine Drainage (AMD) and Reducing Iron (Fe) and Copper (Cu) Content Using Biomass Adsorbents

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Abstract

Mining is an activity that always has an impact on the environment. The adverse effects that cannot be separated from the mining process are mined acid water, where the process of mining acid water occurs due to contact between sulfide rocks and air or water; environmental pollution by mined acid water must be overcome immediately, in the prevention of ecological damage by mine acid water, Various methods are carried out to reduce the impact of mine acid water pollution, one example of a technique that is often used is with limestone channels, where the gaps are filled with limestone fragments to neutralize mine acid water, The method used in this study is an experimental design with an adsorption process. The data collection method in the study uses literature studies, field observations, research preparations, rice husk preparation, coconut coir, and fine coal, Acid Water samples are taken and brought for the testing process. The test results using a pH meter at the Yogyakarta Center for Environmental Health and Disease Control Engineering (BBTKLPP) showed that the pH of AAT was 3.8. Based on the results of the AAS test at BBTKLPP Yogyakarta, the AAT sample contained Fe metal of 130.56 mg/L and Cu of 2.96 mg/L. The highest adsorption effectiveness was in a 3x24 hour adsorbent experiment with a period of 50 grams with a time of pH 45.71%, Fe 98.90%, and Cu 98.71%.

1. Introduction

Mining operations are a significant source of economic development but are often accompanied by environmental degradation, most notably acid mine drainage (AMD). AMD, a prevalent issue associated with mining, occurs when sulfide minerals are oxidized upon exposure to air and water, leading to the formation of highly acidic water containing elevated concentrations of dissolved metals such as iron (Fe) and copper (Cu) [1], [2]. This contaminated water, if not adequately treated, can severely impact aquatic life and degrade water quality, making it unsuitable for agricultural and residential use [3], [4]. Traditional AMD treatment methods often involve passive techniques like limestone channels, which, although economical, have several drawbacks including the requirement for frequent replenishment and their limited effectiveness in fully removing metal contaminants [3]. These methods, while widespread, often fail to meet the stringent environmental standards required to mitigate the impact of AMD on ecosystems [3], [8].

In response to these challenges, there is a growing interest in exploring sustainable and more efficient alternatives. Biomass adsorbents have emerged as a promising solution owing to their low cost, availability, and effectiveness in removing heavy metals from water [4], [5], [6]. Biomass materials such as rice husks, coconut coir, and fine coal have been identified for their potential in adsorption processes. Rice husks are particularly noted for their high lignin and cellulose content, which contributes to their ability to adsorb metals like copper (Cu) and lead (Pb) [5], [10]. Coconut coir has been demonstrated to effectively reduce iron (Fe) levels in water and is advantageous for its fibrous structure and porosity [6]. Furthermore, fine coal, especially when carbonized, presents enhanced adsorption properties due to its increased surface area and affinity for metal ions [7], [9].

This study integrates these three biomass types in a novel approach aimed at improving the efficiency of AMD treatment. By leveraging the unique properties of each biomass material, the research seeks to develop a composite adsorbent that can more effectively neutralize the acidity of mine water and reduce its Fe and Cu content. This is not only crucial for environmental compliance but also for the preservation of local ecosystems and community health [11], [12].

Moreover, the urgency to address AMD has prompted innovations in treatment technologies, exploring both passive and active treatment methods that could be implemented at scale with reduced operational costs [13], [14], [18]. Our approach aims to contribute to this body of knowledge by providing empirical data from field observations, laboratory experiments, and comprehensive literature studies [15], [16], [17].

The expected outcomes of this research could significantly impact sustainable mining practices, offering a cost-effective, environmentally friendly alternative that could be implemented globally to combat the adverse effects of acid mine drainage [19]. This study not only addresses the immediate impacts of AMD but also contributes to the broader dialogue on sustainable mining practices and environmental stewardship.

2. Methodology

Sampling Procedure The research required comprehensive sampling and field data to analyze the effectiveness of biomass adsorbents in neutralizing mine acid water and reducing the concentrations of ferrous (Fe) and copper (Cu) metals. Sampling was conducted at a site where mine acid water had not undergone any prior treatment, ensuring the validity of testing the natural conditions of the AMD. A total of 30 liters of mine acid water was collected for the experiments. Biomass materials were sourced locally: rice husks were obtained from the rice field area in Condong Catur, coconut fiber was sourced from a coconut trader at Concong Catur Market, Kledokan Village, Sleman Regency, Special Region of Yogyakarta, and fine coal was procured from PT. Borneo Indobara, South Kalimantan [16].

Research Hypothesis The hypothesis posits that the selected adsorbents—rice husks, coconut coir, and fine coal—due to their porous morphology, have the potential to effectively increase pH values and decrease the levels of heavy metals Fe and Cu in mine acid water. It is anticipated that the mixture of these biomass adsorbents will significantly enhance the neutralization of acidic water, with increased efficacy correlated to the biomass concentration and contact time during the adsorption process until optimum conditions are reached [4], [6].

Experimental Design and Data Collection The study employed an experimental design focusing on the adsorption process to test the hypothesis. Data collection was structured around several key activities:

a. **Literature Review**: Extensive literature studies were conducted to gather background information and prior research findings related to AMD treatment using adsorption methods. This included reviewing scientific journals, books, and previous research studies that discuss the management and mitigation of mineral acid water through various adsorption techniques [5], [10].
b. **Adsorption Experiments**: Experiments were conducted using an adsorption setup where mine acid water was treated with a mixed biomass of rice husks, coconut fiber, and fine coal. The experiments were designed to assess the pH adjustment and reduction in metal concentrations over varying contact times and biomass concentrations. This methodological approach was informed by previous studies that demonstrated the effectiveness of similar biomass materials in adsorbing heavy metals from aqueous solutions [7], [9].
c. **Data Analysis**: The collected data from the adsorption experiments were analyzed using standard chemical analysis techniques to measure the pH levels and metal concentrations before and after treatment. The effectiveness of the biomass adsorbents was quantified by comparing these parameters, aiming to reach the optimum adsorption conditions [12], [14].

This methodology ensures a rigorous examination of the potential of rice husks, coconut coir, and fine coal as effective biomass adsorbents for treating mine acid water. The structured approach, from sampling to data analysis, is designed to validate the hypothesis and contribute valuable insights into sustainable AMD treatment methods.

a. Field Observation

Field observation is a direct field research activity that directly observes the research area's condition. This research was conducted at PT X Plampang 3, Kalirejo, Kokap, Kulon Progo, Special Region of Yogyakarta.

b. Experiment

i. Tool This research uses the following tools:

- Spatula	- Pulveriser
- Digital Scales	- Glass Funnel
- Pliers Clamp	- Spatula
- Petri Cups	- Sample Plastic
- Desiccator	- Erlenmeyer 500 ml
- Furnace	- Sift size 100 mesh
- Oven	- Filter Paper

ii. Material In this study, the materials used are as follows:

- rice husks taken from the rice field area in Condong Catur.
- coconut coir was obtained from one of the shredded coconut traders at the Concong Catur Market, Kledokan Village, Sleman Regency, Special Region of Yogyakarta.
- fine coal obtained from PT. Borneo, Indobara, South Kalimantan.
- NaOH solution 1000 ml and Aquades 1000 ml

Figure 1. Mine Acid Water Sample Before Treatment

iii. Research Preparation

Preparing the research site, the image of the research site can be seen in Figure 1.2 as follows:

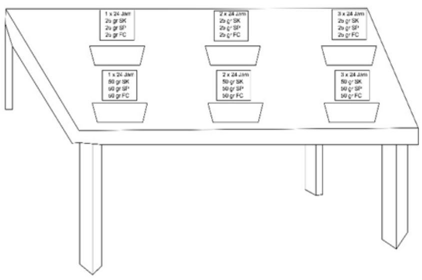

Figure 2. Treatment of samples for 1x24 hours, 2x24 hours and 3x24 hours

iv. Preparation of Rice Husks, Coconut Coir, and Fine Coal

The preparation was carried out to increase the ability of biomass to absorb metals and improve the pH value. Rice husks, coconut coir, and fine coal were prepared at the Coal Laboratory, Department of Mining Engineering, UPN "Veteran" Yogyakarta.

Preparation and activation process of rice husk

- The rice husk was initially washed clean to avoid dirt attached to the rice husk.
- After cleaning, the rice husks are dried in the sun for 6 hours at a hot temperature of 33°C
- Next, dry rice husks in a blender
- After being in the blender, sifting is done with a sieve of 100 mesh to get a homogeneous rice husk size
- After sifting, the rice husk powder will be soaked with NaOH solution for 3 hours, where the NaOH solution used is a mixture of 30%
- After the soaking process, rice husk powder is taken, which is then drained.
- After filtering, the rice husk powder is dried using an oven for 3 hours at a temperature of 120°C
- Furthermore, after being in the oven, the rice husk powder is left in the desiccator for 30 minutes.

Preparation Process and activation of Coconut Coir

- Coconut coir is initially washed clean to remove dirt attached to coconut coir
- After cleaning, coconut coir is then dried in the sun for 6 hours at a hot temperature of 33°C
- Next, the coconut coir is cut into small pieces before being blended to facilitate the blending process
- After blending, sifting is done with a sieve of 100 mesh to obtain a homogeneous size of coconut coir
- After sifting, the coconut coir will be soaked with NaOH solution for 3 hours, where the NaOH solution used is a 30% mixture
- After the soaking process, coconut coir powder is taken and drained.
- After filtering, coconut coir powder is dried using an oven for 3 hours at a temperature of 120°C

Fine Coal Preparation and Activation Process

- Fine Coal is initially washed clean to remove dirt attached to fine coal
- After cleaning, the fine coal is then dried in the sun for 6 hours at a hot temperature of 33°C
- Next, the fine coal will be left for 30 minutes so that the temperature will be stable
- After being left alone, the size of the fine coal is reduced by using a Jaw Crusher to get a smaller size of fine coal
- Furthermore, the results of this preparation will be sifted with a sieve of 100 mesh to obtain a homogeneous fine coal size
- After sieving, fine coal powder will be carbonized to activate the carbon in it
- The activation or carbonization process is carried out with furniture at a temperature of 650°C for 3 hours. Furthermore, the fine coal powder will be left at room temperature in a desiccator for 30 minutes after the furnace

Table 1. Treatment Plant

No	Mass	Time (Hours)
1	25 grams	1x24
2	25 grams	2x24
3	25 grams	3x24
4	50 grams	1x24
5	50 grams	2x24
6	50 grams	3x24

c. Treatment Plan
   In the adsorbent carried out, treatment will be carried out for 3x24 hours, starting from 1x24 hours, 2x24 hours, and 3x24 hours, with two samples in each treatment, using 25 grams of rice husk powder, coconut fibre, and fine coal, and 50 grams of rice husk, coconut fibre, and fine coal, the treatment design can be seen in table 1.
d. The test was conducted at the Coal Laboratory of the Department of Mining Engineering, UPN "Veteran" Yogyakarta.
e. After the adsorbent process is carried out, each sample will be taken and tested according to the contact time and biomass period that has been set, in which each sample is sampled as much as 100 ml to determine the change in pH, as well as Fe and Cu metal conduits to find out the results after the adsorbent process.
f. Laboratory Testing
   i. To determine the pH, Fe, and Cu content after treatment, an *Atomic Absorption Spectroscopy test* was carried out at the Yogyakarta Center for Environmental Health and Disease Control Engineering (BBTKLPP).
   ii. After the *Atomic Absorption Spectroscopy analysis*, *a* Scanning Electron Microscopy *test will be carried out* at the UPN "Veteran" Yogyakarta Integrated Laboratory to analyze the morphology of the biomass surface before and after the treatment
g. Data Analysis
   i. Analysis of Mine Acid Water Samples
      This analysis was used to determine the pH, Fe, and Cu values in mine acid water before and after treatment
   ii. Analysis of Effectiveness and Adsorption Capacity on Adsorbents
      Effectiveness and capacity analysis were carried out to determine the amount of heavy metals absorbed by the adsorbent using equations (5-7).

3. Results and discussions

3.1. Mine Acid Water Test Result

The mining acid water (AAT) used in this study as a test sample came from a treatment site in Plampang 3, Kokap, Kulon Progo, Special Region of Yogyakarta. The acidic water taken from the mining has yet to be treated. Acid water samples are taken and brought in for the testing process. The test results using a pH meter at the Yogyakarta Center for Environmental Health and Disease Control Engineering (BBTKLPP) showed that the pH of AAT was 3.8. Based on the results of the AAS test at BBTKLPP Yogyakarta, the AAT sample contains Fe metal of 130.56 mg/L and Cu of 2.96 mg/L. The sampling image of AAT can be seen in Figure 4

Figure 3. A sampling results of Mine Acid Water

3.2. After Treatment

After adsorption, an AAS test is carried out to determine the pH, Fe, and Cu concentration in mine acid water. This was done to assess the ability of rice husk biomass, coconut coir, and fine coal as adsorbents. The results of the pH test after treatment can be seen in Table 2 and Table 3 as follows:

Table 2. pH results after treatment with a period of 25 grams

Contact Time	Biomass	pH value
1x24 Hours	25 gram Sp, 25 gram Sk, 25 gram Fc	4,6
2x24 Hours	25 gram Sp, 25 gram Sk, 25 gram Fc	5,6
3x24 Hours	25 gram Sp, 25 gram Sk, 25 gram Fc	6,6

Table 3. pH results after treatment with a period of 50 grams

Contact Time	Biomass	pH value
1x24 Hours	50 gram Sp, 50 gram Sk, 50 gram Fc	5,8
2x24 Hours	50 gram Sp, 50 gram Sk, 50 gram Fc	5,9
3x24 Hours	50 gram Sp, 50 gram Sk, 50 gram Fc	7,0

In the results of the pH test after treatment, the pH value by the quality standard, which is 6-7, is in the mixing of biomass of 25 grams of Sp, 25 grams of Sk, 25 grams of Fc with a contact time of 3x24 hours with a pH value of 6.6, and with the mixing of 50 grams of Sp, 50 grams of Sk, 50 grams of Fc with a contact time of 3x24 hours with a pH value of 7.0, From this study, it is concluded that the more biomass used, the better the absorption capacity for the neutralization of mine acid water.
The results of the Fe test after treatment can be seen in Table 4 and Table 5 as follows:

Table 4. Fe results after treatment with a period of 25 grams

Contact Time	Biomass	Value Fe (mg/L)
1x24 Hours	25 gram Sp, 25 gram Sk, 25 gram Fc	0,3248
2x24 Hours	25 gram Sp, 25 gram Sk, 25 gram Fc	1,2446
3x24 Hours	25 gram Sp, 25 gram Sk, 25 gram Fc	2,1622

Table 5. Fe results after treatment with a period of 50 grams

Contact Time	Biomass	Value Fe (mg/L)
1x24 Hours	50 gram Sp, 50 gram Sk, 50 gram Fc	0,4004
2x24 Hours	50 gram Sp, 50 gram Sk, 50 gram Fc	0,4590
3x24 Hours	50 gram Sp, 50 gram Sk, 50 gram Fc	1,4374

In the results of the Fe test after treatment, the Fe value is all by the water quality standard, which is a small amount of 5 mg/L. This shows that the biomass mixture is very effective in absorbing Fe metal from the beginning of the treatment. The treatment with the best Fe reduction is in the 1x24 Hour experiment with biomass mixing 25 grams Sp, 25 grams Sk, 25 grams of Fc contact time 1x24 hours and with the mixing of 50 grams of Sp, 50 grams of Sk, 50 grams of Fc, from this study it was concluded that the use of biomass is very effective for the reduction of heavy metals Fe. The results of the Cu test after treatment can be seen in Table 6 and Table 87as follows:

Table 6. Cu results after treatment with a period of 25 grams

Contact Time	Biomass	Value Cu (mg/L)
1x24 Hours	25 gram Sp, 25 gram Sk, 25 gram Fc	0,0253
2x24 Hours	25 gram Sp, 25 gram Sk, 25 gram Fc	0,0317
3x24 Hours	25 gram Sp, 25 gram Sk, 25 gram Fc	0,0639

Table 7. Cu results after treatment with a period of 50 grams

Contact Time	Biomass	Value Cu (mg/L)
1x24 Hours	50 gram Sp, 50 gram Sk, 50 gram Fc	0,0254
2x24 Hours	50 gram Sp, 50 gram Sk, 50 gram Fc	0,0317
3x24 Hours	50 gram Sp, 50 gram Sk, 50 gram Fc	0,0381

In the results of the Cu test after treatment, the Cu value is all by the water quality standard, which is small from 2 mg/L, this shows that the biomass mixture is very effective in absorbing Cu metal from the beginning of the treatment, the treatment with the best Cu reduction is in the 1x24 Hour experiment with biomass mixing 25 grams of Sp, 25 grams of Sk, 25 grams of Fc contact time 1x24 hours and with the mixing of 50 grams of Sp, 50 grams of Sk, 50 grams Fc of contact time 1x24 hours, from this study it was concluded that the use of biomass is very effective for the reduction of heavy metals Cu.

3.3 Result of the SEM (Scanning Electron Microscopy)

This will be analyzed before and after treatment with mixed biomass of 50 grams of SP, 50 grams of SK, and 50 grams of FC with a contact time of 3x24 hours. This is because the best results of the adsorbent are in the treatment and mass, and the morphological image shows that the adsorbent has a porous morphology. In Figure 4, the morphology of the adsorbent surface before and after adsorption can be seen.

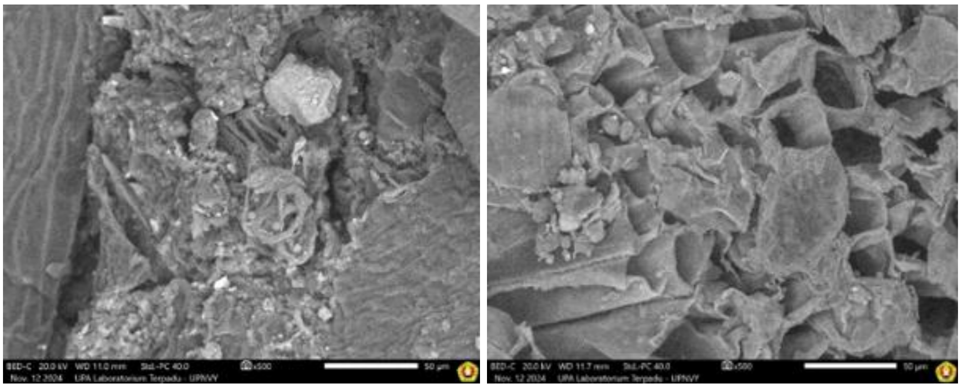

Figure 4. Biomass Surface Morphology Before (left) and After (right) 500 x Magnification

The experimental results of this study demonstrate the potential of using a combination of rice husk, coconut coir, and fine coal as effective adsorbents for the treatment of mine acid water. The testing procedures and results indicate significant improvements in the pH, and reductions in Fe and Cu concentrations, bringing these within acceptable environmental standards. These outcomes are supported by a robust experimental design and contribute to a growing body of research on biomass adsorption technologies.

pH Neutralization: The improvement in pH levels from a highly acidic initial pH of 3.8 to near-neutral levels (up to pH 7.0 in some tests) underscores the effectiveness of the biomass mixtures used. This pH adjustment is crucial for mitigating the corrosive and toxic nature of mine acid water, as low pH levels can lead to significant environmental damage [4], [6]. The increase in pH also aligns with previous studies indicating the buffering capacity of similar biomass materials [5], [10].

Iron (Fe) Reduction: The significant decrease in iron concentrations in treated samples, with levels well below the water quality standard of 5 mg/L, highlights the strong adsorptive properties of the biomass. These results are consistent with prior findings where biomass materials efficiently adsorbed metal ions from aqueous solutions [7], [9]. The lowest observed concentration of Fe (0.3248 mg/L after 24 hours with 25 grams of each biomass type) suggests an optimal contact time and biomass amount for maximum adsorption, providing crucial insight into the operational parameters for upscaling this treatment method.

Copper (Cu) Reduction: Similar to iron, the reduction in copper levels to well below the 2 mg/L standard further validates the use of this biomass combination. The effective removal of copper, particularly in the experiments where lower concentrations were achieved with shorter contact times, underscores the potential for rapid treatment deployments in field conditions [12], [14]. This finding is particularly relevant given the toxic effects of copper on aquatic life and its tendency to accumulate in the environment.

Scanning Electron Microscopy (SEM) Results: The SEM analysis before and after treatment provides visual confirmation of the adsorptive interaction between the biomass materials and the metal ions. The observed changes in the surface morphology of the biomass—indicating pore filling and surface binding of metal ions—correlate with the mechanical and chemical interactions expected in adsorption processes [15], [17]. This microscopic evidence supports the hypothesis that surface area and porosity are critical factors in the efficacy of biomass adsorbents.

Implications for Future Research and Application: These results not only demonstrate the feasibility of using biomass for mine acid water treatment but also suggest that such methods can be optimized for better performance through variations in biomass type, mixture ratios, and contact times. Further research could explore the long-term stability of these biomass adsorbents and their performance in continuous flow conditions, which are more representative of real-world applications [18], [19].

4. Conclusion

The comprehensive suite of tests and experiments conducted within this study provides robust evidence supporting the effectiveness of biomass adsorbents in the management of mine acid water. Through the application of a 50-gram mixture of rice husk, coconut coir, and fine coal in a 3x24-hour adsorption experiment, the results illustrate a substantial improvement in water quality. The pH of the mine acid water was successfully neutralized, increasing from an acidic 3.8 to a near-neutral 7.0, which aligns with the optimal conditions for most aquatic life and reduces the corrosivity of the water.

Furthermore, the concentrations of harmful metals were significantly reduced, with iron (Fe) levels decreasing from 130.56 mg/L to 1.4374 mg/L, and copper (Cu) levels from 2.9562 mg/L to a minimal 0.0381 mg/L. These reductions represent a removal efficiency of 98.90% for Fe and 98.71% for Cu, indicating a highly effective treatment capable of reducing these metal concentrations to levels that are generally considered safe for environmental discharge.

The Scanning Electron Microscopy (SEM) analyses corroborate these findings by displaying the porous morphology of the biomass adsorbents, which is critical for the adsorption process. The visual evidence from SEM supports the hypothesis that the physical structure of the biomass contributes significantly to its ability to trap and retain heavy metal particles.

This study's findings underscore the potential of using sustainable biomass materials as low-cost, effective solutions for treating mine acid water. By transforming what are often agricultural by-products into valuable resources for environmental management, this approach not only addresses the pressing issue of pollution from mining activities but also contributes to the circular economy. Future studies could expand on this work by exploring the scalability of the treatment, long-term stability and reusability of biomass adsorbents, and their efficacy under different environmental conditions, which will be crucial for broader application in field settings.

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