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Neutralization of Galena Acid Mine Water Using CaO and $CaCO_3$ at PT Berkat Bhinneka Perkasa

Taufiq Zulhaji Sam[1], Mukhlis[2], T. Alief Aththorick[3], Hamidah Harahap[4], Said Muzambiq[5]

[1]Natural Resources and Environmental Management Study Program, Universitas Sumatera Utara, Indonesia
[2]Department of Agrotechnology, Faculty of Agriculture, Universitas Sumatera Utara, Indonesia
[3]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara, Indonesia
[4]Department of Chemical Engineering, Faculty of Engineering, Universitas Sumatera Utara, Indonesia
[5]Department of Environmental Engineering, Faculty of Engineering, Universitas Sumatera Utara, Indonesia

e-mail: taufikzulhajisam.st@gmail.com

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Abstract
The mining system implemented at PT. Berkat Bhinneka Perkasa is an underground mining system. The results from mining the metal mineral commodity black lead ore (PbS/Galena) are helpful in the battery industry, color pigments, ammunition, cable coatings, radiation protection, solder, and other materials that use Pb and Zn as basic ingredients. This research examines the neutralization of acid mine drainage using Tohor Lime (CaO) and Calcium Carbonate Lime (CaCO3). The methods used are survey and experimental techniques, where the survey involves field observations to determine observation points and collect data. In contrast, the experimental method includes laboratory analysis followed by data analysis. This research shows that acid mine wastewater with pH 4.74 and 240.20 ppm Fe^{2+} was effectively treated using quicklime, calcium carbonate, TKKS, and rice husk biochar. These ameliorants significantly increased pH and met the river water quality standards per Government Regulation 22 of 2021. Although active ferrous levels also increased, the effect was not statistically significant. However, excessive ferrous content can harm agricultural soils and plants, potentially causing iron toxicity.

Keywords: Acid mine drainage, Calcium Carbonate Lime (CaCO3), Quick Lime (CaO)

INTRODUCTION

The environmental impact of galena (PbS) mining, particularly concerning acid mine drainage (AMD), is significant. Waste rock and tailings from mining and refining processes can lead to severe ecological consequences if not properly managed. Galena mining operations produce substantial amounts of waste rock and tailings (Zendelska et al., 2022). When these materials are exposed to air and water, sulfide minerals like galena oxidize, forming sulfuric acid. This acidification process can leach heavy metals, including lead, into surrounding water bodies, resulting in AMD (Huaman et al., 2023). The U.S. Environmental Protection Agency (EPA) notes that AMD is a prevalent form of water pollution in mining regions, adversely affecting aquatic ecosystems and water quality.

The ecological ramifications of AMD are profound. A study by the U.S. Geological Survey (USGS) on streams in southeast Missouri found that sediments downstream of lead-zinc mining areas exhibited significant toxicity. This toxicity was linked to elevated concentrations of metals such as lead, zinc, and cadmium, reducing aquatic organisms' survival rates. Human health is also at risk due to AMD. Contaminated water sources can lead to the accumulation of heavy metals in the food chain (Rey et al., 2021). In Ghana, research on the Bonsa River revealed that illegal mining activities had led to mercury and lead concentrations exceeding safe limits, rendering the water unsafe for consumption (Obiri-Yeboah et al., 2021).

Preventive measures are crucial to mitigate AMD's impact. Techniques such as covering waste rock to limit exposure to air and water, and treating contaminated water with neutralizing agents like lime, are effective strategies. The EPA emphasizes the importance of such interventions in preventing the formation and spread of AMD. Implementing lime treatment, specifically using quicklime (CaO) and calcium carbonate ($CaCO_3$), has proven effective in neutralizing acidic waters resulting from mining. This method raises the pH of contaminated water, facilitating the precipitation of dissolved heavy metals such as lead, arsenic, and cadmium (Lombardo et al., 2022). A study by the Indonesian Ministry of Energy and Mineral Resources (KESDM) in collaboration with research universities has demonstrated that applying lime treatment in post-mining areas can reduce metal concentrations by up to 90%, making it one of the most practical remediation techniques for AMD in developing countries.

In addition to chemical treatment, constructed wetlands have gained attention as a more sustainable and ecological approach to AMD management (Hassan et al., 2021). These engineered systems mimic natural wetlands and utilize plants, soil, and microbial activity to filter and detoxify contaminated water. Countries such as Canada and Germany have successfully integrated these systems into former mining sites, reporting significant improvements in water quality over time. Though the initial investment can be high, constructed wetlands offer long-term environmental and economic benefits by reducing the need for continuous chemical input.

Community involvement and regulatory enforcement are vital to ensure the effective management of AMD. Mining companies ' transparency in environmental monitoring and consistent reporting of water quality can build trust with local populations. Government agencies must also enforce environmental compliance strictly. For instance, Indonesia's Ministry of Environment and Forestry (KLHK) has issued Regulation No. P.68/MenLHK/Setjen/Kum . 1/8/2016, which mandates effluent standards for mining wastewater (Hutagalung & Kurnani, 2021).

PT. Berkat Bhinneka Perkasa is a private company engaged in mining metallic minerals, specifically lead ore (PbS/Galena), in Indonesia. The company's mining area is located in Kanagarian Tanjung Balit, Pangkalan Koto Baru District, Limapuluh Kota Regency, West Sumatra Province, covering an area of 104.7 hectare (Pamungkas et al., 2023). Established with a focus on the extraction of lead ore, PT. Berkat Bhinneka Perkasa intends to contribute to the local economy by providing mining products while ensuring sustainable practices. In addition to its core business, the company is committed to responsible environmental management. PT. Berkat Bhinneka Perkasa adheres to the regulations set by the Ministry of Energy and Mineral Resources (KESDM) to maintain high safety and environmental standards.

The urgency of addressing the environmental impact of galena mining, particularly acid mine drainage (AMD), cannot be overstated. The potential for severe ecological degradation increases as the demand for lead and other metallic minerals rises globally. The lack of effective waste management practices and the exposure of sulfide minerals to air and water exacerbate the formation of AMD, leading to irreversible damage to local ecosystems and water resources. In regions like West Sumatra, where mining operations are concentrated, developing and implementing mitigation strategies that prevent AMD and protect water quality is critical. Additionally, gaps in current environmental monitoring and the inconsistent application of remediation techniques highlight the need for more effective and sustainable solutions.

The primary objective of this research is to evaluate the effectiveness of various AMD management strategies, with a specific focus on neutralization treatments using lime, at PT. Berkat Bhinneka Perkasa's mining site. The study aims to enhance the company's environmental stewardship while mitigating the risks associated with AMD by assessing the current practices and identifying potential improvements.

RESEARCH METHODS

Location and Time of Research

The research will be carried out from March to May 2023, at the lead ore mining company (PbS/Galena) PT. Thanks to Bhinneka Perkasa, which administratively includes mines in the Kanagarian Tanjung Balit area, Pangkalan Koto Baru District, Limapuluh Kota Regency, West Sumatra Province.

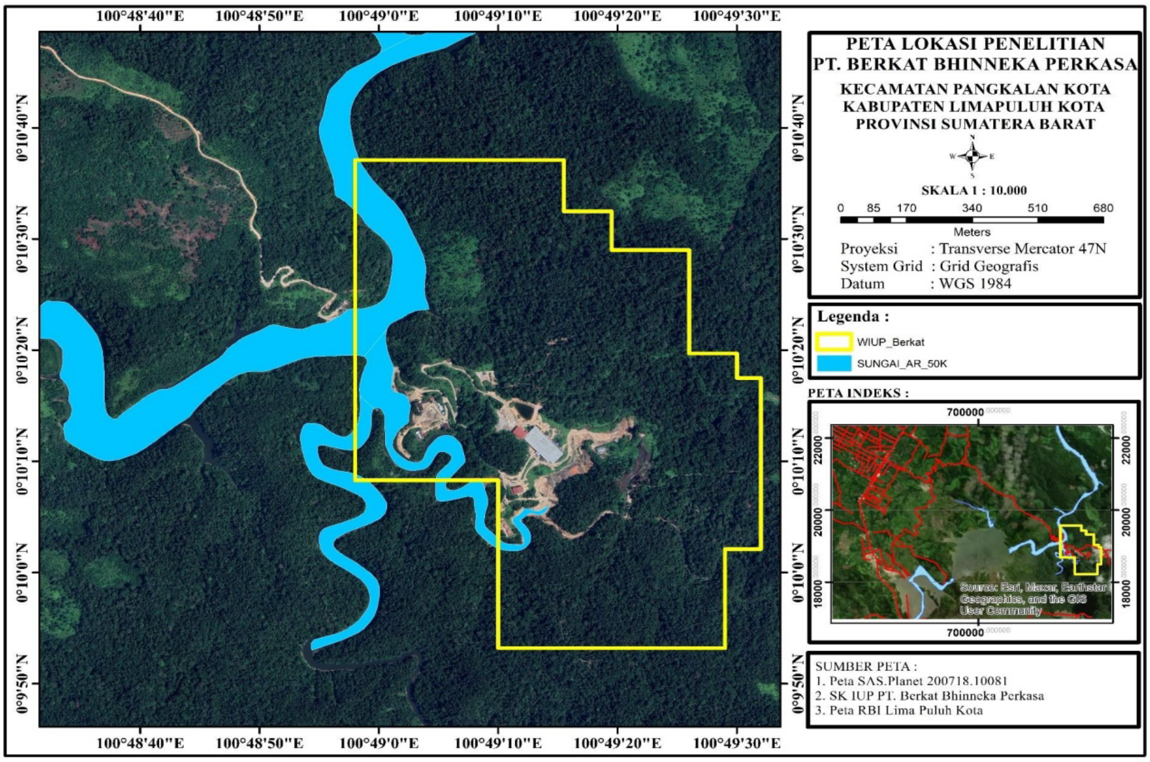

Figure 1. Research Sites

Tools and Materials

1) Tools

a) Field data collection tools:
- 1-liter sample bottles
- pH meters

b) Laboratory equipment
- Measuring cups for measuring the volume of acid mine water and solutions
- Analytical scales for weighing materials
- Series bottles as containers for observation
- Paper labels for marking each treatment
- pH meters for measuring the pH of water
- Spectrophotometers for measuring active ferrous content analysis (Fe2+)
- Camera
- Plastic bag
- Beaker glass
- Analytical balance
- Label paper
- Laptop

2) Materials

a) Acid mine drainage (AMD) is the material to be treated
b) Quicklime (CaO)
c) Calcium carbonate lime ($CaCO_3$) as the treatment material
d) Distilled water
e) Other chemicals used for analysis in the laboratory

Laboratory Analysis

Laboratory analysis is used to determine the pH value of acid mine water by mixing the ingredients of Tohor Lime (CaO), Calcium Carbonate Lime (CaCO3)

a) Preliminary analysis of wastewater

An initial waste analysis was carried out as data to support the research. Initial wastewater analysis uses two parameters, namely pH H2O (Electrometric Method) and Active Ferro Fe2+ (Spectrophotometric Method).

b) Sample testing

The acid mine drainage sample was put into a glass beaker; each beaker was filled with 50 mL of the acid mine drainage sample. The beaker glass containing 50 mL of acid mine water sample was measured for the acidity level without mixing neutralizing agents, then treated using quicklime (CaO) at doses of 0.5g, 1.0g and 1.5g at each sample station in the beaker glass, 50 mL of acid mine drainage. Treatment of Calcium Carbonate Lime (CaCO3) with acid mine drainage, put into a glass beaker, involves 50 mL of water, given doses of 0.5g, 1.0g, and 1.5g for each sample station. Each treatment was measured when the pH changed to neutral. The test used a randomized block design (RAK) with treatment consisting of:

K: Control, (Acid Mine Water without treatment)
H1: Acid Mine Water + Quicklime (CaO) 0.5g/50mL
H2: Acid Mine Water + Quicklime (CaO) 1.0g/50mL
H3: Acid Mine Water + Quicklime (CaO) 1.5g/50mL
L1: Acid Mine Water + Calcium Carbonate Lime (CaCO3) 0.5g/50mL
L2 : Acid Mine Water + Calcium Carbonate Lime (CaCO3) 1.0g/50mL
L3: Acid Mine Water + Calcium Carbonate Lime (CaCO3) 1.5g/50mL

The treatment combination was carried out in 3 repetitions. So, the total experimental units are 13 x 3 = 39.

Observation Parameters

The research observation parameters consist of:

a) pH H_2O (Electrometric Method)

Acid mine water samples that had been incubated for 14 days were

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then analyzed for pH H2O using the electrometric method with a pH meter.

b) Active Ferro Fe2+ (Spectrophotometric Method)
A sample of acid mine drainage was incubated for 14 days, then 2 ml of acid mine drainage was taken and 50 ml of pH 2.8 was added. After mixing, 2 ml of the filtrate was taken, 5 ml of pH 6.0, and 3 ml of α.α dipyridyl solution were added. , and then read with a spectrophotometer with a wavelength of 525 nm.

Types and Sources of Data

This research utilizes both primary and secondary data:

a) Primary data was collected through questionnaires distributed to MSME actors to gather information on energy consumption (electricity, LPG, and fuel) and business income.
b) Secondary data was obtained from the Central Bureau of Statistics (BPS) 2023, the Ministry of Environment (KEMENLH), the Directorate General of Electricity of the Ministry of Energy and Mineral Resources (ESDM) 2018, and the IPCC 2006 guidelines.

Data Analysis Techniques

Calculate Primary and Secondary Emissions from the Use of Electricity, LPG, and Transportation Fuels. The calculations are based on the IPCC 2006 methodology using the following equations:

1) Primary Carbon Footprint from LPG Usage

$$\text{LPG carbon footprint} = \text{Fuel consumption} \times EF \times NCV$$

Information:
LPG carbon footprint = Total of GHG emissions from LPG usage (Ton CO2 eq)
Fuel consumption = (Kg/month)
EF = Emission factor (Kg/TJ)
NCV = Net Calorific value per unit volume of fuel (TJ/Kg)

2) Primary Carbon Footprint from Fuel Usage

$$\text{Fuel carbon footprint} = \text{Fuel consumption} \times EF \times NCV$$

Fuel carbon footprint = Total of GHG emissions from LPG usage (Ton CO2 eq)
Fuel consumption = (liters/month)
EF = Emission factor (Kg/TJ)
NCV = Net Calorific value per unit volume of fuel (TJ/Kg)

3) Secondary Carbon Footprint from Electricity Usage

$$\text{Electricity carbon footprint} = EFCO_2 \times \text{Electricity consumption (KWh)}$$

Electricity carbon footprint = Total GHG emissions from electricity usage (Ton CO2eq)
EF = CO2 emission factor
Electricity consumption = (kWh)

$$\text{Total Carbon Footprint (Ton CO2eq)} = \text{Primary Carbon Footprint (Ton CO2eq)} + \text{Secondary Carbon Footprint (CO2eq)}$$

Emission Factor is a value that represents the amount/quantity of pollutants emitted into the atmosphere by an activity. This research will use the emission factors set nationally/regionally and the default IPCC values.

Table 1. Emission Factor and NCV Values

No.	Emission source	Faktor Emisi	NCV	Sumber
1.	Electricity Consumption	0,00089 Ton CO_2 KWh	-	Director General of ElectricityESDM 2018
2.	Fuel Consumption	74.100 Kg CO_2/TJ	33×10^{-6}TJ/L	*Default* IPCC (KEMENLH, 2012)
3.	LPG Consumption	CO_2 17.200 Kg GRK/TJ CH_4 5 kg GRK/TJ N_2O 0.1 kg GRK/TJ	$47,3\times10^{-6}$ TJ/Kg	*Default* IPCC (KEMENLH, 2012)

The Global Warming Potential (GWP) value converts non-CO2 greenhouse gas emissions data into carbon dioxide equivalent (CO2eq).

Table 2. The GWP Values for Each Greenhouse Gas (GHG)

No.	Gas	GWP (CO_2eq)
1.	Carbon Dioxide ((CO_2)	1
2.	Methane (CH_4)	21
3.	Nitrous Oxide (N_2O)	298

The processing of questionnaires as primary data is also used to identify factors that influence the carbon footprint of MSME activities. This processing utilizes statistical tests with the SPSS program, which helps to find the correlation between income and carbon footprint and between LPG, fuel, and electricity expenditures and the carbon footprint produced in the research area. Additionally, statistical tests are conducted to determine whether sufficient evidence exists to accept or reject the hypothesis.

A linear regression analysis of income against carbon footprint is performed to assess the effect of income as an independent variable on the carbon footprint as a dependent variable. The data must undergo basic assumption tests, including normality and linearity tests. Subsequently, multiple regression analysis examines whether LPG, fuel, and electricity energy consumption impact the carbon footprint. A t-test is performed in multiple regression to determine whether the independent variables have a partial (individual) effect on the dependent variable..

Acid Mine Water pH Results

The provision of ameliorant materials in the form of quicklime (CaO), calcium carbonate lime ($CaCO_3$), oil palm empty fruit bunch biochar (TKKS), and rice husk biochar was able to show a real effect on the pH of acid mine water. The following can be seen in Figure 2.

RESULTS AND DISCUSSION

Research Result

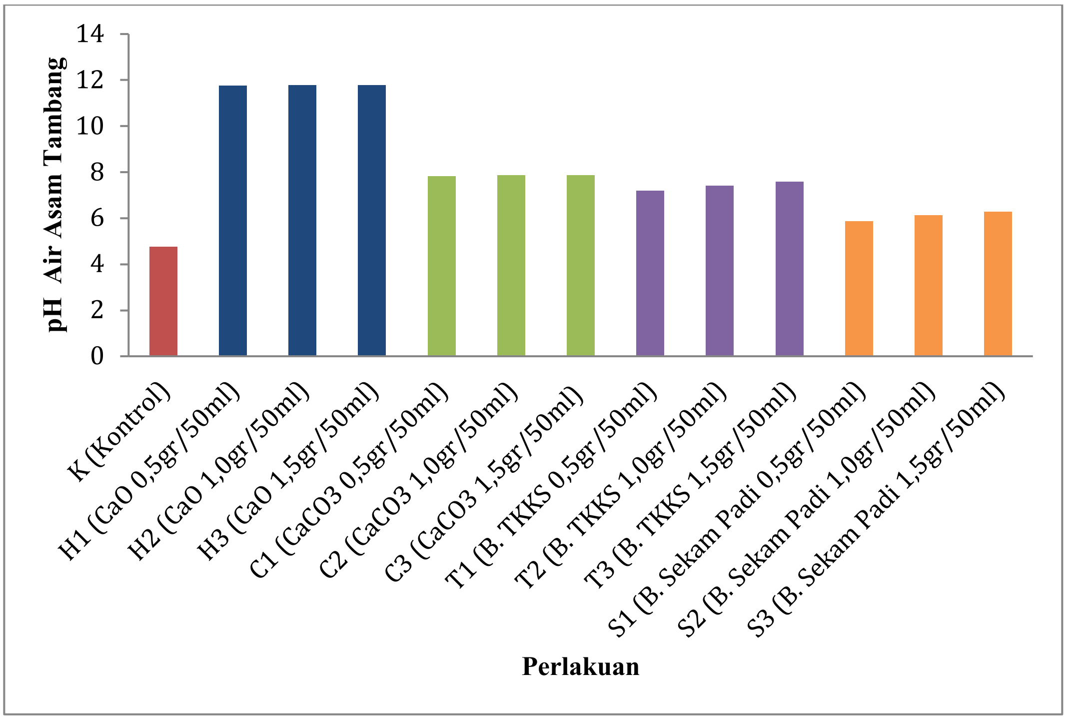


Figure 2. pH of Acid Mine Water

Figure 2 shows that the lime and biochar treatment increases the pH as the dose increases, from a control of 4.74, it increases to 11.75 for quicklime (CaO), rising to 7.87 for calcium carbonate lime ($CaCO_3$). The acid mine water's pH increase after ameliorant treatment is due to the alkalinity of lime and biochar. Hossain et al (2013) stated that biochar generally has alkaline properties due to alkalis and metal bases in the raw material that do not evaporate during pyrolysis.

Active Ferro Acid Mine Water

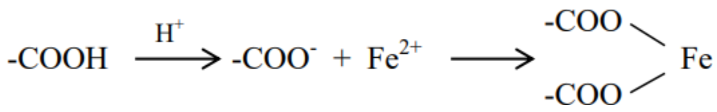
The provision of ameliorants in the form of quicklime (CaO), calcium carbonate lime (CaCO3), oil palm empty fruit bunch biochar (TKKS), and rice husk biochar increased the active ferrous content of acid mine drainage, but did not have a significant effect. The active ferrous content of acid mine water in the control was 240.20 ppm, increasing to 349.17 ppm for quicklime (CaO), rising to 685.18 ppm for calcium carbonate lime (CaCO3), increasing to 548.96 ppm for oil palm empty fruit bunch biochar (TKKS), and increased to 285.60 ppm for rice husk biochar.

Based on research results, the application of lime ameliorant is included in the basic (alkaline) pH criteria. Based on Government Regulations, the Republic of Indonesia has determined water classes through Government Regulation Number 22 of 2021. This explains that water used to irrigate crops is in class 4, with a quality standard pH value of 6-9. Alkaline irrigation water contains a lot of hydroxide ions, which can reduce the absorption of substances needed by plants. Apart from that, it can also damage plant cells so that the metabolism of the cells is disrupted, and it reduces the ability to absorb nutrients.

In line with the increase in the pH of acid mine water, applying lime and biochar ameliorant also increased the active ferrous acid mine water. Still, statistically, it did not have a significant effect. Adding lime causes a drastic increase in active ferro because when it reacts with iron pyrite, it releases sulfate, and the lime will bind the sulfate.

$$CaO + FeSO_4 + H_2O \rightleftharpoons Fe(OH)_2 + CaSO_4$$
$$CaCO_3 + FeSO_4 + H_2O \rightleftharpoons Fe(OH)_2 + CaSO_4 + CO_3^{2-}$$

Based on research results, adding ameliorant to ferrous levels that are too high can have dangerous impacts when disposed of on agricultural land. From a needs aspect, Fe is a micronutrient for plants, typically contained in plant tissue in the range of 100-200 ppm. Iron poisoning results from high iron concentrations in the soil (250 ppm to 550 ppm) and high iron concentrations in plants (300-500 ppm).



Effect of Ameliorant Application on pH of Acid Mine Water

The treatment of acid mine water with various ameliorant materials, including quicklime (CaO), calcium carbonate lime ($CaCO_3$), and biochars, notably increased the pH of the water, indicating the effectiveness of these materials in neutralizing the acidity of the water. The addition of quicklime showed the most significant pH increase, reaching a value of 11.75, while calcium carbonate lime raised the pH to 7.87. These results were consistent with previous research, (Lee et al., 2022) emphasizing that biochar typically has alkaline properties due to alkalis and metal bases that do not volatilize during pyrolysis. The increase in pH is attributed to the alkaline nature of lime and biochar, which, through their reaction with H+ ions, neutralize the acidity in the mine water.

Research Petronijević et al. (2022) also support the findings that alkaline lime solutions contain hydroxide ions (OH^-), which react with the hydrogen ions (H^+) from acidic mine drainage. This interaction, where OH^- ions bind with H^+ ions, is responsible for the increase in pH. The results of the current study demonstrate that with the increasing doses of lime and biochar, the pH of the acid mine water progressively improves, making it more alkaline. These findings are crucial because proper pH management of mine drainage is necessary to prevent environmental damage, such as metal leaching and soil contamination, which can occur when mine water remains highly acidic.

Further research, such as (Maintang et al., 2022) others, has emphasized the importance of managing pH levels in agricultural irrigation. They reported that water with a pH level exceeding 9, as seen with lime-treated acid mine drainage, could negatively affect plant health by reducing nutrient absorption and damaging plant cells. Therefore, while lime and biochar treatments can effectively raise pH, careful monitoring is needed to ensure that the pH does not exceed levels that would make the water unsuitable for agricultural use. These results indicate the potential for environmental applications but also highlight the need for balancing neutralization treatments to ensure safety for both the ecosystem and human use.

The application of lime in acid mine water treatment is a solution to address environmental concerns and a demonstration of sustainable practices in mining operations. Properly managing acid mine drainage can prevent long-term ecological damage, such as soil acidification and heavy metal contamination. However, this study also highlights the importance of considering the pH range required for different environmental and agricultural applications.

Influence of Ameliorants on Active Ferro Content in Acid Mine Water

The treatment of acid mine water with various ameliorants, including quicklime (CaO), calcium carbonate lime ($CaCO_3$), and biochars, affected the pH levels and influenced the active ferrous content. The study results show that applying lime-based ameliorants resulted in an increase in active ferrous (Fe^{2+}) concentrations. Quicklime raised the ferrous content to 349.17 ppm, while calcium carbonate lime caused a rise to 685.18 ppm. These increases are linked to the chemical reactions between the ameliorants and ferrous minerals in the acid mine water, specifically the reaction with iron pyrite (FeS_2) that releases sulfate ions, which in turn bind with lime, forming insoluble compounds such as $Fe(OH)_2$ and $CaSO_4$.

In a similar research (Ambarsari et al., 2023), applying lime-based materials to neutralize acid mine drainage also showed increased ferrous concentrations. Still, the authors emphasized that this increase may not always be desirable. Excessive ferrous content in the water can pose environmental risks, particularly when the water is discharged into agricultural areas. High iron concentrations can lead to toxicity, negatively affecting plant growth and soil health. The increase in ferrous levels observed in this research highlights the need to balance the neutralizing effects of ameliorants with the potential for heavy metal accumulation, which could pose risks to ecosystems and human health.

Moreover, while the results indicate a positive effect regarding pH neutralization, the rising concentrations of active ferrous in treated acid mine water suggest that additional measures might be required to ensure safe discharge into agricultural land. Excessive iron concentrations can lead to iron toxicity in plants, as observed by (Kautsar, 2019) iron poisoning, which was noted at concentrations ranging from 250 ppm to 550 ppm in soil. At such high concentrations, plants can suffer from nutrient imbalances, decreased growth, and even death due to iron accumulation in their tissues. This raises concerns about the long-term sustainability of lime treatments for acid mine drainage in agricultural zones.

To mitigate these risks, further research is needed to develop treatment strategies that neutralize acid mine water and prevent the accumulation of harmful levels of ferrous iron. Research (Mymrin et al., 2021) suggest that alternative treatment methods, such as using organic materials in combination with lime, could reduce the ferrous content in the water while maintaining its effectiveness in neutralizing acidity. Constructed wetlands or biofiltration systems incorporating both chemical and biological treatments might offer a solution to reduce acidity and metal content.

CONCLUSION

The MSME with the highest income is the smashed fried chicken business, with an average income of IDR 19,225,000/month, while the MSME with the lowest income is the siomay business, with an average income of IDR 7,700,000/month. The MSME with the highest LPG consumption is the smashed fried chicken business, using 95.4375 kg/month, or approximately one gas cylinder per day. At the same time, the lowest is the siomay business, which uses 33 kg/month or one gas cylinder every three days. The MSME with the highest fuel consumption is the smashed fried chicken business, which consumes about 15 liters/month, and the lowest is the fried food business, which consumes approximately 4 liters/month. The MSME with the highest electricity consumption is the restaurant, which uses 173 kWh per month, while the lowest is the noodle business, which uses 60 kWh per month.

The MSME with the highest GHG emissions is the restaurant, generating approximately 3.079 tons of CO2eq/year, followed by the smashed fried chicken business at 2.682 tons of CO2eq/year, and the meatball business at 2.504 tons of CO2eq/year. In the linear regression test, income has a significant influence of 93.3% on the carbon footprint, with a positive relationship between income and carbon footprint. Management strategies that can be implemented include analyzing the stages of the production process that require significant energy, allowing for formulating strategies to reduce the emissions generated. Typically, energy waste in production is caused by overproduction, transportation, inventory, waiting, scrap/defect, and overprocessing.

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