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Evaluation of Quicklime Dose, Stirring Speed, and Reaction Time for Coal Mine Acid Water Treatment

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ABSTRAK

Air asam tambang dari penambangan batu bara menimbulkan tantangan lingkungan yang signifikan karena keasamannya yang tinggi dan kandungan logam beratnya. Studi ini mengevaluasi efektivitas kapur tohor (CaO) sebagai agen penetral untuk menangani AAT, yang bertujuan untuk mengoptimalkan parameter utama penanganan: dosis penetral, kecepatan pengadukan, dan waktu reaksi. Eksperimen batch laboratorium dilakukan menggunakan sampel representatif air asam tambang sebanyak 200 liter yang dikumpulkan dari pembuangan lubang tambang. Investigasi tersebut menentukan bahwa dosis kapur tohor optimal sekitar 0,145 g/L, dikombinasikan dengan kecepatan pengadukan 100 rpm dan waktu reaksi minimum 30 detik, secara efektif menyesuaikan pH air dalam kisaran target 6,5 hingga 7,5. Hasil menunjukkan bahwa peningkatan kecepatan pengadukan di atas 100 rpm dan perpanjangan waktu reaksi di atas 30 detik memberikan perbaikan pH yang marginal. Skala temuan ini untuk aplikasi praktis memperkirakan kebutuhan kapur tohor sekitar 86,1 kg per jam untuk menangani 700 m^3/jam air asam tambang. Dengan demikian, studi ini memberikan pedoman konkret untuk netralisasi AAL yang efisien, menggabungkan presisi laboratorium dengan kelayakan skala lapangan untuk mendukung kepatuhan lingkungan dan pengelolaan air tambang yang berkelanjutan.

Kata Kunci: Pertambangan, Air Limbah, Lingkungan Hidup, Batubara

ABSTRACT

Acid mine drainage from coal mining poses significant environmental challenges due to its high acidity and heavy metal content. This study evaluated the effectiveness of quicklime (CaO) as a neutralizing agent for treating acid mine drainage, aiming to optimize key treatment parameters: neutralizer dosage, stirring speed, and reaction time. Laboratory batch experiments were conducted using 200 liters of representative acid mine drainage samples collected from mine pit discharges. The investigation determined that the optimal quicklime dosage of approximately 0.145 g/L, combined with a stirring speed of 100 rpm and a minimum reaction time of 30 seconds, effectively adjusted the water pH within the target range of 6.5 to 7.5. The results showed that increasing the stirring speed above 100 rpm and extending the reaction time beyond 30 seconds improved the marginal pH. Scaling these findings to practical applications estimates the requirement of approximately 86.1 kg of quicklime per hour to treat 700 m^3/hour of acid mine drainage. Thus, this study provides concrete guidelines for efficient neutralization of AAL, combining laboratory precision with field-scale feasibility to support environmental compliance and sustainable mine water management.

Keywords: Mining, Wastewater, Environment, Coal

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1. INTRODUCTION

Mining is a business sector that always causes changes in the surrounding natural environment, such as damage to habitat and biodiversity around mining sites, mining waste and tailings disposal, wastewater and acid mine water discharge, chemical management, security and exposure to chemicals on site, heavy metal toxicity, and the health of communities and settlements around the mine (Rukmana, 2017). Coal mining is generally carried out using open pit mining, although some use underground mining. This will impact changes in the natural landscape and the chemical, physical, and biological properties of the soil (Maulana, 2020)If not appropriately manage, coal mining activities commonly can lead to damage in the earth's surface (IESR, 2019). Several aspects of coal mining include the formation of acid mine drainage, where water that comes into contact with rocks in the mining area will have acidic properties with a pH < 5 (Guntoro, 2023). Acidic water occurs when water flows over or across sulfide rock containing sulfur and forms an acidic solution. Acid water is generally formed in mining activities that have been or are currently operational, referred to as acid mine water (Rohit Rathour, 2019). East Kalimantan, with 34% of its land containing coalm is particularly vulnerable to the environmental impacts of mining, especially acid mine drainage. This can be reflected in the significant decline in the river water quality index in the region. In 2018, the river water quality index in East Kalimantan showed an excellent value of 86.19, but it has since deteriorated considerably (Hernandi, 2021).

The presence of acid mine drainage and high acidity levels can cause corrosion of pipes and buildings, damage walls, as well as kill plants and other aquatic organisms if water contaminated with acid mine drainage flows into water bodies and disrupts human health (Munawar, 2017). Waters with a pH value of 7 are neutral, while waters with a pH below 7 are acidic (Natarajan, 2018). Water that has an acidic pH below 4 is the death point for fish, whereas at a pH < 6 causes slow fish growth, and at a pH of 5, it is an acidity level that results in fish being unable to reproduce (Said & Yudo, 2021)S. The generation of acid mine drainage from the mining process must be appropriately managed to reduce the impact on the environment around the mine. In general, the management of acid mine water is done by using a neutralization method with the addition of materials or chemicals that have alkaline properties so that the wastewater that will be channeled into public channels already has a pH that meets the established quality standards (Skousen, 2019). If effective management of mininf wastewater is not implemented, it will cause a decrease in the water quality index of the Mahakam River in East Kalimantan. This deterioration would threaten the sustainability of aquatic habitat and negatively impact the surrounding communities, many of whom rely on the river for raw water, fish farming, and a daily necessity.

The decline in river water quality due to pollution from mining activities, which can flow into the river without management, will impact community health conditions (Anekwe, 2023). People's habits include using public water for daily needs, such as bathing, washing, and using toilets, and some people even use river water for consumption. Based on these conditions, the researcher is interested in researching acid mine drainage processing methods based on dosage, quicklime, speed, and duration of stirring at the acid mine drainage treatment plant produced by the Company of X open-pit coal mining activities in East Kalimantan. The researcher expect that this research can help communities around mining locations reuse the results of acid mine drainage for their daily activities. This research was carried out to analyze the effectiveness of the acid mine water treatment process with a quicklime neutralizing agent and determine the water quality test for the community and the environment. The specific objectives of this research are to determine the most effective dosage levels for adding quicklime (CaO), choose the speed, duration of stirring, and the most optimal dosage for the acid mine drainage treatment process, and determine the results of water quality tests before it is released into rivers and its utilization for the surrounding community.

Among alkaline neutralizing agents, Tohor Lime (quicklime, CaO) is widely used. In this study, the term "Tohor Lime" refers to a locally available form of quicklime commonly produced and used in Indonesia. Its relevance lies in its cost-effectiveness, wide availability in mining regions, and proven efficacy in neutralizing acidic mine water compared to other alkaline agents such as sodium hydroxide or limestone Using Tohor Lime ensures both scientific reliability and practical feasibility for large-scale application in East Kalimantan. This research specifically investigates three operational parameters dosage, stirring speed, and stirring duration because they directly influence the neutralization efficiency, mixing uniformity, and reaction kinetics of the quicklime treatment process. Optimizing these parameters is essential to achieve pH values that meet environmental discharge standards and to minimize chemical use and treatment costs. Accordingly, this study aims to determine the most effective dosage of Tohor Lime (quicklime, CaO), identify the optimal stirring speed and duration, and evaluate treated water quality against regulatory standards to support environmentally safe wastewater management in coal mining areas.

2. MATERIALS AND METHODS

This study employed descriptive quantitative research design with analytical techniques using experimental methods to determine the neutralizing dose, stirring speed, stirring time, and pH produced from the acid mine drainage. The population of this study consisted of acid mine water released from the pit of Company X, collected from the settling pond. This research utilized the latest method for processing acid mine water, using a sample volume of 1 liter. Samples were taken from the intake of the acid mine water treatment plant, using 200 liters plastic drum container that was thoroughly cleaned before use. Each test involved stirring the drum to ensure that the sample kept homogeneous and exhibited consistent characteristics. Each variable treatment was tested in three repetitions. The standard water quality test, focused on acid mine drainage, was carried out with a 5 liters jar test. The research was scheduled to take place between June to Oktober 2024.

2.1. Research Instrument

1. Acidity Level (pH) of Acid Mine Water

This is a tool for measuring the acidity level (pH) of acid mine water using a Partech type 740 W pH meter. The tool was calibrated using pH buffer solutions pH 4.0, 7.0, and 10.0. The pH reading results on the pH meter display were recorded in a notebook. Them, the pH reading was taken at the beginning of the acid mine drainage sampling and recorded as the initial pH. After the treatment process, the reading for each variable was also recorded as the final pH.

2. Dosage of Neutralizing Agent

The tool used in this research is a scale. The neutralizing agent was added with varying weights of 0.05, 0.1, 0.15, 0.20, and 0.25 grams for each acid mine drainage sample. Each of these neutralizing chemicals were added to 1 liter of acid mine drainage. The weight of this neutralizing chemical added was recorded on the record sheet.

3. Stirring speed

The tool used in this research is a jar test tool with an adjustable speed setting. The scale on the stirring speed button on the jar test tool was used to treat different stirring speeds, namely at speeds of 20, 50, 100, and 200 rpm. Speed differences were measured for each test, and then the mixing speed scale was recorded on a note sheet.

4. Stirring time

The tool used in this research is a stopwatch to calculate the time required for each treatment of the acid mine drainage sample. Treatment the stirring time in the acid mine drainage processing process is 10, 30, 60, 240, 360, 600, and 900 seconds.

2.2. Data Collection

The data used in this research is primary data obtained through direct data collection in the field during the Jar test implementation by the sample treatment conducted.

1. Data Collection Procedures

The process for collecting data in the research was through acid mine water treatment trials using the latest method. The latest steps are as follows:

I. Taking a sample of 1 liter of acid mine water in a beaker, then measuring the water's initial pH; the reading was then recorded on the record sheet as the initial pH.
II. Then, they were treated according to the variables, including:
   a. Quicklime was added with varying weights of 0.05, 0.1, 0.15, 0.20 and 0.25 grams.
   b. Stirring was carried out with variations in stirring according to the speed of the latest tool, namely 20, 50, 100, and 200 rpm. The optimal addition of lime used the dose obtained from the first variable (dose of neutralizing agent).
   c. Stirring was carried out with varying stirring times, namely 10, 30, 60, 240, 360, 600, and 900 seconds, with the addition of optimal lime from the first variable (dose of neutralizing agent)
III. The next step was to read the pH using a pH meter for each variable and record the pH on a note sheet with the final pH code.

1. Processing Techniques

The data obtained from the jar test results were classified into a notes table using a column to record the variations of each variable and the pH reading of the treatment carried out. Data were repeated three times for each treatment.

2. Data Processing

In the analysis process, the data obtained for each treatment was looked at for data from 3 replications and did not produce data with substantial differences (no outliers occurred). If the data showed a high spread, it was necessary to repeat the jar test on that variable.

3. Data input

The data obtained was entered in a notes table based on each variable treatment carried out in the research. Then, the data input process was carried out using the SPSS application using a linear regression approach.

4. Graphic Creation

A linear regression graph was obtained from the data processing results using linear regression, with the x-axis being the treatment for each variable. At the same time, the y-axis referred to the pH reading after treatment. The researcher got the regression equation formula of y = a + bx, and t the coefficient of determination (r2).

5. Calculation

The optimal treatment for acid mine drainage could be determined from the regression equation formula obtained. The formula obtained is y = a + bx by entering the desired pH value in the process as the x value, the dose of added lime, stirring speed, and stirring time will be found. As a result, a prediction of the most effective treatment for acid mine drainage could be obtained. Apart from that, the r value was also found, showing the correlation between these variables' treatment and the achievement of pH in acid mine drainage treatment. The r value was compared with the reference to see the correlation.

2.3. The pH meter Calibration

The data in this research were obtained using equipment whose validity and reliability were guaranteed. Before using the pH meter, it was calibrated using a buffer solution of pH 4.0, 7.0, and 10.0.

2.4. Data Analysis

a. Simple Linear Regression Test

Simple linear regression analysis models were the correlation between a dependent variable and an independent variable, which was linear, where changes in x variable were regularly followed by changes in y variable.

b. Correlation Coefficient Analysis

Correlation coefficient analysis determines how closely the correlation is between two variables, which shows the strength of the correlation between the independent variable (x), namely the treatment of acid mine drainage (dose of neutralizing agent, stirring speed, stirring time, and properties of the neutralizing agent), with the dependent variable (y), namely the achievement of the pH of the treated water. This corrected approach avoids the previous misstatement of using target pH as the independent variable. Instead, regression equations were used to predict the treatment variable required to achieve the desired pH. pH was measured using a Partech 740 W pH meter, calibrated before each set of tests using standard buffer solutions at pH 4.0, 7.0, and 10.0. Initial pH was recorded prior to treatment, and final pH was measured immediately after each treatment.

c. Laboratory Analysis

Laboratory analysis was carried out at the Regional Health Laboratory of the Tangerang City Health Service to examine the physical test parameters (Smell, Temperature, Color, Turbidity, Total Dissolved Solids) and chemical tests (Iron, Nitrate, Nitrite, pH, dissolved Manganese, CaCO3, Zn, Fluoride, and Sulfate). This analysis was carried out to observe the results of sample tests with the maximum levels of clean water quality standards according to the Republic of Indonesia Minister of Health Regulation Number 32 of 2017.

3. RESULTS AND DISCUSSION

3.1. Dosage, Speed , and Time for Mixing Tohor Lime, Laboratory Test

The treatment involving variable dose of lime addition was carried out by equalizing the stirring speed to 200 rpm, which is the maximum stirring speed in the latest tool, with the stirring time was 300 seconds. Variations in the dosage of quicklime added to 1 liter of acid mine drainage were varied at 0.05, 0.1, 0.15, 0.20, and 0.25 grams (as shown in Table 1). The correlation test (r) results were obtained at 0.994, indicating a strong positive relationship between the duration of adding the quicklime dose and the pH achieved from processing. A positive r value correlation indicates a positive relationship, meaning that increasing the dose of quicklime leads to a higher pH in the treated water, while reducing the dose results in a lower pH. Regression test results used the regression equation Y = 3,596 + 23,523x (table 2). The -P significance value was obtained at 0.0001. This indicates that the -p value <0.05, so it can be concluded that there is a significant correlation between the stirring time and the pH value after treatment. Adding 0.15 grams indicates that the pH value has reached a pH close to 7.0. Thus, the value for adding the lime dose used in the subsequent treatment is 0.15 grams/liter (fig.1).

Table 1. The Jar Test Results with Various Doses of Tohor Lime

No	Addition of Lime	Dosage (mg/ L)	Initial pH	pH Reading			
				1	2	3	Average
1	0	0		3.57	3.59	3.58	3.58
2	0.05	50	3.57	4.85	4.91	4.81	4.86
3	0.075	75	3.52	5.04	5	5.05	5.03
4	0.1	100	3.59	6.33	6.18	6.1	6.20
5	0.125	125	3.62	6.58	6.56	6.59	6.58
6	0.15	150	3.58	6.91	7	7.03	6.98
7	0.2	200	3.58	7.73	8.4	8.32	8.15
8	0.25	250	3.59	9.67	9.56	9.61	9.61

Table 2. Correlation and Linear Regression of Tohor Lime Dosage on pH

Variable	r	r^2	Regression Equation	-p
Additional Dose of Lime	0.994	0.987	y=3.596 + 23.523x	0.0001

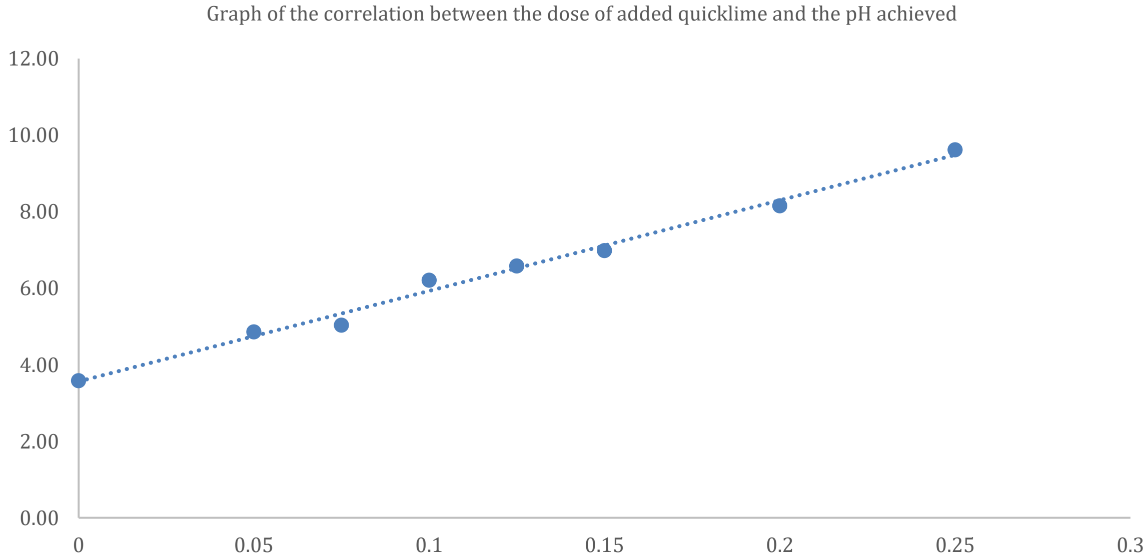

Figure 1. Tohor Lime Addition Dosage Chart

The correlation test on the data obtained from the jar test shows that the correlation coefficient (r) value is 0.994. This shows a solid correlation between the dose of added quicklime and the pH achieved from processing. With the r^2 value obtained, the value is 0.987, which can be interpreted as indicating that the magnitude of the variation in the pH value variable. It can be explained by the variable of adding a dose of quicklime, is 98.7%. The additional dose of lime affects the processing results. By adding quicklime, the regression equation of y=3.596 + 23.523x was obtained. Using this equation, the additional dose needed to treat acid mine drainage at company 7.00 could be predicted, thus adding 0.145 grams of quicklime is necessary. As a result, this shows that the characteristics of acid mine drainage in different locations have different dosage requirements for quicklime. The additional time required is 0.145 grams of quicklime for 1 liter of acid mine drainage, it can be interpreted that for 1 m3 of wastewater, 0.145 kg of quicklime is needed. Then, with a wastewater flow rate of 700 m^3/hour, 101.5 kilograms of quicklime is required per hour. For implementation conditions in the field, lime was added without considering the incoming wastewater discharge. The addition was carried out every 10 minutes for one sack so that in 1 hour, around six sacks or 150 kg/hour were added.

Stirring speed treatment was performed with variations at 20 rpm, 50 rpm, 100 rpm, and 200 rpm. In adding a 0.15-gram dose of quicklime to 1 liter of acid mine water, with an initial average pH of 3.58, different pH levels were observed after varying the stirring speed treatment. Without stirring, the pH did not change. However, with a stirring speed of 20 rpm, the pH increased to 4.71; at 50 rpm, the pH increased to 5.12; at 1rpm, the pH further increased to 7.13 (see Table 3). Meanwhile, the maximum stirring speed of the latest tool, namely 200 rpm, resulted an increase in pH to 7.38. A correlation test was carried out on the data obtained from the jar test, indicated the correlation coefficient (r) value of 0.909, demonstrating a strong positive correlation between the stirring speed and the pH achieved from processing. A positive r value indicates a positive correlation, meaning that as the speed of stirring increases, the pH of the processing will also show a higher value (Fig.2).

Conversely, slower stirring results in the lower pH. The results of the linear regression test showed that the regression equation was y=4.215 + 0.019x (see Table 4). The p-significance value obtained was 0.0001; it can be seen that the p-value <0.05, so it can be concluded that there is a significant relationship between the stirring speed and the pH value after treatment. The stirring speed has a correlation coefficient (r) of 0.909, which shows a solid relationship between the stirring speed and the pH achieved from processing. The faster the stirring speed, the quicker the solute will dissolve in the solvent.

Table 3. Jar Test Results with Various Stirring Speeds

No	Addition of Lime (gram)	Mixing Speed (rpm)	pH Reading			
			1	2	3	Average
1		0	3.58	3.59	3.57	3.58
2		20	4.71	4.7	4.73	4.71
3	0.15	50	5.2	5.02	5.15	5.12
4		100	7.14	7.15	7.1	7.13
5		200	7.29	7.4	7.46	7.38

Table 4. Correlation between Linear Regression Analysis of Speed and pH

Variable	r	r^2	Regression Equation	-p
Speed of Stirring	0.909	0.826	y=4.215 + 0.019x	0.0001

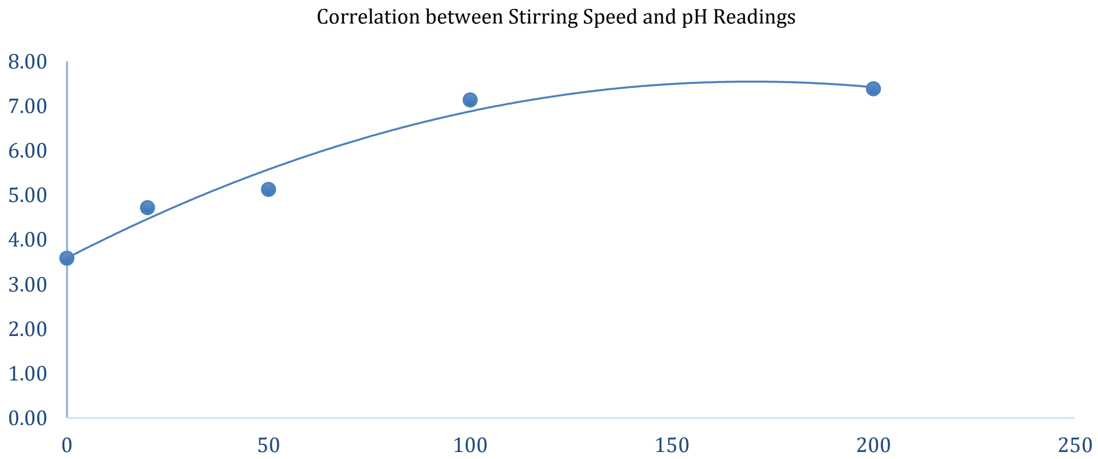

Figure 2. Graph of Stirring Speed with pH

Treatment for the variable duration of stirring time was carried out on samples of acid mine drainage by adding a dose of quicklime of 0.15 grams each to 1 liter of acid mine drainage and stirring at a speed of 200 rpm. The stirring time varied at 10, 30, 60, 240, 360, 600, and 900 seconds (as shown in Table 5). pH stirring at 200 rpm for 10 seconds, the pH increased to 3.61. After stirring at 200 rpm for 10 seconds, the pH was increased to 6.38. After the 60-minute stirring treatment, there was an increase of 7.21 and an increase with the long stirring treatment. After 10 minutes of stirring, the pH increased to 7.75.

Acid mine water is water that is formed as a result of mining activities with a low pH (pH < 6) due to the exposure of sulfide minerals in rock to water and oxygen during mining activities, which negatively impacts water and soil quality (see Fig.6). A correlation test on the data obtained from the jar test showed that the correlation coefficient (r) value of 0.515, indicating a moderate correlation between the stirring time and the pH achieved from processing. The graph demonstrates a significant pH increase up to 30 seconds of stirring, after which the rate of increase levels off.

The trial calculation yielded an r2 value of 0.265, suggesting that 26.5% of the variation in pH can be attributed to stirring duration. This indicates a need to explore additional variables affecting pH outcomes. Future research should consider the interaction between stirring duration and stirring speed to optimize pH adjustments. The maximum concentration value taken was based on the regulations of the Republic of Indonesia Minister of Health Regulation Number 32 of 2017, dated 31 May 2017, concerning Environmental Health Quality Standards and Water Health Requirements for Sanitation Hygiene, Swimming Pools, Aqua Solution, and Public Baths 9 (see Table 7). The results of tests carried out using physical and chemical parameters indicate that water that has undergone the process of adding quicklime that can be used by people who live around the mining site as a means for their daily needs.

Quicklime, a chemical compound composed of calcium oxide (CaO), is produced by burning raw lime (calcium carbonate or CaCO3) at approximately 90^{0}C. When mixed with water, quicklime produces heat and becomes into hydrated lime (calcium hydroxide, CaOH) (Lesbani et al., 2016).

Table 5. Jar Test Results with Stirring Time

z	Addition of Lime (grams)	Duration of Stirring (Second)	Reading of pH			
			1	2	3	Average
1		0	3.59	3.61	3.62	3.61
2		10	6.34	6.39	6.4	6.38
3		30	7.13	7.14	7.18	7.15
4		60	7.22	7.22	7.2	7.21
5	0.15	120	7.24	7.28	7.29	7.27
7		240	7.34	7.39	7.35	7.36
8		360	7.42	7.42	7.45	7.43
9		600	7.63	7.58	7.61	7.61
10		900	7.75	7.79	7.7	7.75

Table 6. Correlation between Linear Regression of Stirring Time and pH

Variable	r	r^2	Regression Equation	-p
Duration Stirring	0.515	0.265	y=6.325 + 0.002x	0.006

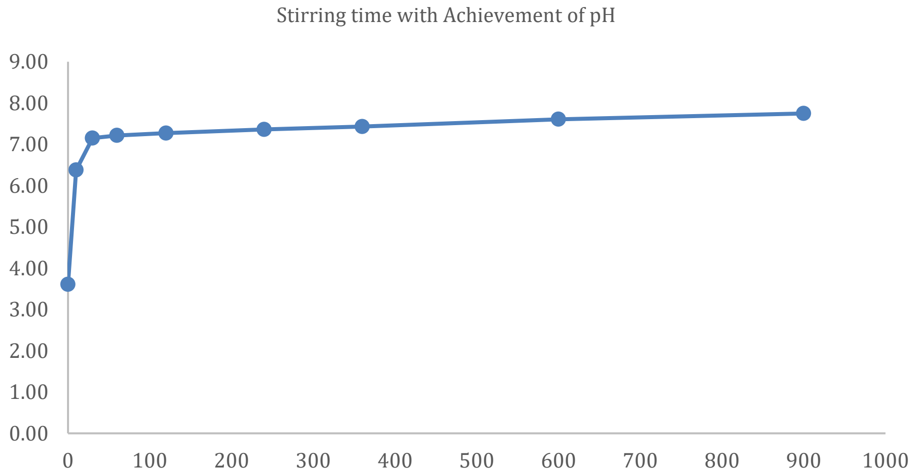

Figure 3. Graph of Stirring Time with Achievement of pH

Table 7. Physics and Chemistry Laboratory Test Results

Parameter Checked	Unit	Maximum Level Allowed	Result Checked	Method
Physics (clean water)				
Smell	-	Odorless	Odorless	Organoleptic
Temperature***	°C temperature	±3°C	23.0	SNI 06-6989.23-2005
Color	TCU Scale	50	2	IK.LKT-09/L15
Turbidity*	NTU Scale	25	1.01	SNI 06-6989.25-2005
Total Dissolved Solids (TDS)*	mg/L	1000	44.6	IK.LKT-09/L27 (Electrometry)
Chemistry (Clean Water)				
Iron (Fe) dissolved *	mg/L	1	0.052	IK.LKT-09/L7 (Spectrofotometry)
Nitrate(N03-N)*	mg/L	10	<0,06	IK.LKT-09/L35 (Spectrofotometry)
Nitrite(N02-N)	mg/L	1	0.001	IK.LKT-09/L37
pH***	-	6,5-8,5	8.10	SNI 6989.11-2019
Dissolved Manganese	mg/L	0.5	0.017	IK.LKT-09/L4 (Spectrofotometry)
Hardness (CaC03)*	mg/L	500	359.43	IK.LKT-09/L16
Dissolved zinc (Zn)*	mg/L	15	0.044	IK.LKT-09/L10 (Spectrofotometry)
Fluoride (F)*	mg/L	1.5	0.47	IK.LKT-09/L6 (Spectrofotometry)
Sulfate*	mg/L	400	217.73	IK.LKT-09/L13 (Spectrofotometry)

The formation of acid mine drainage is primarily influenced by various factors, such as water, air, and materials containing sulfide minerals that are exposed during mining mineral operations. The generation of acid mine drainage has a significant and vital impact on the environmental and surrounding communities' sustainability directly and indirectly (Vola et al., 2023)In open mining systems, there is an excellent potential for acid mine drainage to form because it is in direct contact with free air, so the factors that can form acid mine drainage will react more efficiently.

The reaction between quicklime and water has been historically utilized for low cost cooking application (Paes et al., 2024). This study differs from research conducted by Wildania Sholikah, who found that the amount of quicklime (CaO) needed to neutralize acid mine water is 0.104 g/L with an initial inlet pH of 2.93 to 7,20 (Surchat et al., 2023). However, in practical applications, the addition is not based on the pump discharge, leading to an excessive application rate of 150 kg/hour regardless of the incoming wastewater volume. As a result, the lime dosage remains inefficient, compared to optimal results observed in the Jar test results (Eriksson et al., 2024).

The results of the r^2 calculation obtained a value of 0.826; indicating that the magnitude of the variation in the pH value variable that the stirring speed variable can explain is 82.6%. The stirring speed affects the processing results (Mosai et al., 2024). In the Company's acid mine water treatment process, a substantial amount of quicklime settles without dissolving, leading to waste and substandard treatment results (Bandara et al., 2020). Unlike quicklime, which is highly soluble in water, -andesite, a type of igneous rock, is much less soluble, making it less effective in increasing the pH of acid mine water (Zhao et al., 2024)The faster the stirring speed and the smaller the grain of the solute, the quicker the solute will dissolve, enhancing the treatment process in (Masindi et al., 2022). For effective treatment, the Company's wastewater treatment facility may require enhanced mixing techniques, possibly incorporating static stirring using water flow if it exceeds 100 rpm.

Based on the actual mixing time in the field in processing acid mine drainage at the Company, there needs to be additional mixing time so that the quicklime will dissolve before it enters the settling Pond. The mixing process could be done by increasing the length of the acid mine drainage flow when lime was added before entering the settling Pond. Assuming the adequate time is 30 seconds, the residence time in the mixing process required a flow length of 15 meters. Therefore, the path length for mixing the acid mine drainage with quicklime is less than 10 meters long. The flow path for mixing acid mine drainage with quicklime could be made to achieve a distance of at least 15 meters. From the quality testing results, the time variable can influence the acid neutralization process. The longer the mixing time, the longer the reaction time (speed) between the limestone and acid mine water will be, so the quality of the resulting water will be better (the pH will be higher) (Firman, 2021).

3.2. Laboratory Test Results

Physical and chemical test were conducted on wastewater samples tested with quicklime. Physical tests included sensory evaluation using organoleptic methods for odor parameters through human senses (Ismanto, 2023) and electrometric methods for dissolved solids (TDS) tests. The examination results of the physical parameters stated that the wastewater was below the quality standards set out in the Republic of Indonesia Minister of Health Regulation Number 32 of 2017 concerning environmental and water health standards. After that, the parameters examined were chemical, such as Iron (Fe), Nitrate, Nitrite, pH, Dissolved Manganese, Hardness, Zinc (Zn), Fluoride, and Sulfate. The method were performed using spectrophotometry, which measured the interaction of energy and matter to determine the concentration of a solution through the absorption intensity at a wavelength (Pratiwi & Nandiyanto, 2022). The chemical parameter test results reveal that the inspection results were below the established quality standards. This states that people in the surrounding environment can use waste water from mining for sanitation, etc. However, it is not suitable for drinking water purposes. Further studies are needed regarding the results of the quicklime addition test, and wastewater treatment technology should be explored for further utilization.

4. CONCLUSIONS

The research identifies 0.145 grams of quicklime per liter as the optimal dose for neutralizing acid mine water, based on thorough statistical analysis and practical jar test experiments. A stirring speed above 100 rpm and a contact time exceeding 30 seconds have proven effective in achieving a neutral pH, with all parameters shown to be directly supported by the presented data. For industrial application, this translates into a quicklime requirement of 101.5 kg per hour for a flow of 700 m^3/hour. The findings highlight the importance of maintaining efficient mixing—either by static means or using mechanical mixers—to address previous inefficiencies and ensure rapid chemical reactions. Furthermore, a 15-meter channel for mixing is recommended, ensuring adequate time for the neutralization process to occur. Finally, clarity on units is emphasized, with the appropriate dose being 0.145 grams per liter, aligning with standard water treatment practices.

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