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# EFFORTS TO IMPROVE THE QUALITY OF QUICKLIME IN HANDLING ACID MINE DRAINAGE: A CASE STUDY AT PT. TCM

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**Abstract**

*The aim is to make the use of quicklime more effective in processing Acid Mine Drainage (AMD), through efforts to improve the quality of quicklime, look for new sources of quicklime that are suitable for acid mine drainage processing, and reduce costs while maintaining quicklime's ability to raise the pH of waste water according to standards. environmental quality. The research methodology uses data processing (Pareto analysis & Ishikawa diagrams to find the root of the problem then test validity with liner regression) and uses tests to test quicklime's ability to lower pH. Efforts made to improve the quality of Quicklime can reduce the quantity needed for Quicklime by up to 350%, the ability to increase the pH of acid mine water increases, and can reduce production costs for PT. TCM. The research approach takes the form of concrete strategies needed to improve the quality of quicklime in handling AMD, especially in the context of handling AMD from coal mines.*

**Keywords**: Quicklime; Quality Improvement; Acid Mine Drainage; Environmental Quality Standards; Wastewater Treatment

## Introduction

Coal plays a crucial role in supporting national development, serving as a strategic resource. However, extensive coal mining can have detrimental environmental impacts if waste is not managed correctly. One significant consequence is the formation of Acid Mine Drainage (AMD), which arises from intricate physical and chemical processes and leads to the creation of acidic water. When AMD reacts with the sulfide minerals from rock layers, it can decrease the pH of the water and bond with any heavy metals it encounters (Lindsay et al., 2015; Muchamad et al., 2021; Nishimoto et al., 2021).

Recent studies indicate that while coal mining contributes substantially to a country's economic growth, it can also lead to numerous environmental challenges (Afkarina et al., 2019). The environmental challenges such as water pollution, management costs, regulatory compliance, supervision and monitoring, company reputation, stakeholder concern, technology and innovation, and climate change. One of the most frequent issues is the formation of AMD, produced by the interaction between water and the soil's sulfide minerals (Tomiyama et al., 2019; Yuan et al., 2022).

The impact of AMD on the environment, especially on surface water and soil systems, can be severe. When AMD infiltrates water systems, it can harm aquatic life due to its extremely low pH and contamination from dissolved heavy metals. In Indonesia, regions with intensive mining activities have reported AMD contamination in local rivers and lakes, affecting drinking water quality and freshwater ecosystems. Some of mining companies using SIMPEL application that can show online report about licensing of environmental field for businesses and/or activities.

In response, the Indonesian government has issued several regulations and guidelines directing mining companies to manage and mitigate AMD risks. Peraturan Daerah or Local Government Regulation (2011) of East Kalimantan No. 2 about managing water quality and wastewater air polluttion obligate mining company to measure the wastewater around their place using some of parameters such as TSS, pH, Fe and Mangan. However, implementation often faces various challenges, whether technical, economic, or social. This highlights the need for collaborative efforts between the government, industries, local communities, and other stakeholders to address the AMD issue (Li et al., 2022; Pauna et al., 2023; Thisani et al., 2021).

AMD must be treated to ensure it meets quality standards before being discharged into public rivers. The quality and quantity of treated water should be regularly monitored. According to the Indonesian Ministry of Environment's Decision (2003) No.113 to avoid environmental contamination, AMD's pH should be maintained between 6 and 9. Companies often add Quicklime (CaO) to treat AMD and meet these standards (Sari et al., 2018). Quicklime is a chemical that neutralizes AMD. It's introduced directly into the water in precise, controlled amounts, effectively raising the pH.

PT. TCM, a coal mining company in East Kalimantan, Indonesia, reports very low AMD pH levels, averaging around 3.2. To meet the required standards before discharging into public rivers, the company uses 45 kg of Quicklime per cubic meter of water, raising the pH from 3.2 to 7.00. This approach is not efficient as it requires large amounts of Quicklime, leading to high costs. Therefore, solutions are sought to use Quicklime more efficiently and reduce operational costs, such as enhancing the quality of Quicklime used. This could yield optimal results with reduced Quicklime costs and quantities.

Previous research explained that quicklime can be used on wastewater treatment (Sholikah et al., 2017). Another research also shows that by using product from quicklime manufacturing can be used potentially in treating acid mine drainage (Tolonen et al., 2014). Different result is explained by Assyakiri et al., (2022) the required dose of quicklime with an average pH of 4.31 doesn't meet environmental quality standards based on Indonesian Ministry of Environment's Decision (2003) No.113. Another research also inform that the composition of the mixture of fly ash and quicklime as much as 0.30 grams had no effect on the TSS parameters of acid mine drainage (Rahmi et al., 2023).

Although there has been a lot of previous research examining the problem of AMD, there is still a gap in understanding the concrete strategies needed to improve the quality of acid mine water, especially in the context of treating AMD from coal mines. Previous research tends to focus more on identifying pollution sources and the chemical characteristics of acid mine water, while few studies specifically discuss the practical implementation of remedial strategies for handling AMD in coal mines.

In the context of a case study at PT. TCM, previous studies have also not provided a comprehensive picture of the challenges faced by these companies in overcoming AMD problems in their coal mining operations. There is a need to fill this gap with more in-depth research, which will provide insight into specific strategies that can be implemented to improve the quality of acid mine water from coal mines as well as identify the constraining factors that may affect the successful implementation of these strategies. This research aims to analyze measures to enhance Quicklime's quality in handling AMD, allowing companies to use Quicklime more efficiently. From the text above, the questions of this research are :

a. Does quality control affect Quicklime's quality?
b. Does sourcing Quicklime from non-primary manufacturers affect its quality?
c. Does sourcing Quicklime from only one producer impact its quality?
d. Can quality analysis influence Quicklime's quality?

This research has made a significant contribution in several crucial aspects. First, this research provides practical guidance for the lime mining industry by identifying concrete strategies to improve the quality of acid mine drainage. Second, this research complements the literature with a case study that describes the handling of acid mine drainage from coal mines. This is important because the current literature lacks concrete examples that can be used as references by researchers and industry practitioners alike. Third, this research identifies potential inhibiting factors in the implementation of improvement strategies. This information will provide valuable guidance for industry and regulators in anticipating and overcoming future obstacles. Fourth, by providing guidance on improvement strategies, this research has the potential to reduce the negative environmental impacts generated by mining waste in line with the principles of sustainability. Finally, the contribution of this research also includes a scientific aspect by providing empirical data from case studies that complement the literature on handling acid mine drainage, providing a stronger basis for the development of more effective and sustainable strategies in dealing with AMD problems.

## Methods

This study employs both Quantitative and Qualitative research methods. Specifically, it utilizes Pareto Analysis, Cause and Effect Analysis through the Ishikawa method, and analyzes the interrelationship between variables using Simple Linear Regression.

### *Pareto Analysis*

The objective of this analysis is to categorize the quality of the currently used quicklime based on its cost requirements. In this study, the actual quality of quicklime is tested with weight variations sourced from TCM, aiming to neutralize acid mine water without undergoing dissolution and mixing processes.

1. Collect approximately 7 liters of water samples from Pit 3000, Block 10 NB.
2. Measure the initial pH of the water sample using a pH meter.
3. Divide the water sample into seven parts, with each portion consisting of about 1 liter of water placed in separate containers.
4. Stir the water sample in each container and add varying weights of quicklime samples to them. Stir for 1 minute.
5. Measure the pH of the water in each container starting from the first hour up to the 24th hour.
6. Record the pH rise in each container after every measurement.
7. Analyze the pH attainment based on each weight of the quicklime.

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8. Calculate the cost of the quicklime required to neutralize the acid mine water to determine the necessary quantity of quicklime and the associated cost.

This methodology offers a structured approach to understanding the relationship between quicklime's quality and cost, the effects of varying its quantity on water pH, and the cost-effectiveness of its application in acid mine water neutralization.

*Root Cause Analysis*

This research is a case study focused on PT. TCM in East Kalimantan. It aims to analyze the causes and effects of the subpar quality of quicklime currently used by PT. TCM. The objective is to identify the root issues and suggest improvements. A case study strategy is most appropriate when research questions are related to "how" or "why", especially when researchers have minimal control over the phenomena under investigation. Data was collected through direct fieldwork, involving observations and primary data gathering by interviewing PT. TCM employees directly involved in the planning, supplier selection, procurement, distribution, and use of Quicklime. Subsequently, the data was interpreted by identifying the reasons for the decline in Quicklime quality and linking it with other components using fishbone analysis or the Ishikawa diagram.

*Analysis of Variable Relationships*

This study employs Simple Linear Regression, aimed at gauging the strength and direction of the relationship between two variables: the independent and dependent variables. The dependent variable in this study is Quicklime Quality.

*Dependent Variable*

The quality of Quicklime in neutralizing acid water can be measured based on:

a. Its ability to increase pH: The higher the potential of quicklime to enhance water pH, the better its quality.
b. Absorption capacity: A quicker water absorption process indicates superior quicklime quality.
c. Quantity required to adjust water pH: The lesser the amount needed to elevate water pH to standard levels, the higher the quality of the Quicklime.

*Independent Variable*

Factors analyzed in relation to the dependent variable (Quicklime Quality) based on fishbone analysis include:

a. Quicklime quality control.
b. Sourcing of Quicklime from non-primary manufacturers.
c. Sole sourcing of Quicklime from a single producer.
d. Absence of prior Quicklime quality analyses.

To examine each variable, observations and data collection were conducted on the case study of acid mine water treatment using Quicklime at PT. TCM. The collected data was then processed and compared using MS Excel to analyze the relationship between each test variable and the quality of investigated Quicklime, based on the shown correlation coefficient.

## Results and Discussion

*Quicklime Overview*

Quicklime (CaO), also known as calcium oxide, has shown potential for AMD treatment (Tolonen et al., 2014). It's effective due to its calcium and hydroxide ion (OH) content, which can react when dissolved in water, thereby increasing pH and reducing heavy metal content. Its characteristics include a molecular weight of 56.08 g/mol, varying colors due to impurities, and a melting point of 2,580 ºC. Chemically, Quicklime has exothermic reactions with water, forming calcium hydroxide. It can also interact with metals and carbon under specific conditions. Quicklime's potential to enhance the pH of AMD and reduce heavy metals such as chromium, cadmium, and arsenic in coal processing waste.

*Acid Mine Drainage (AMD) Overview*

AMD is acidic water characterized by a low pH, less than 6 (Hidayat, 2017). It forms when sulfide minerals react with air and water. This acidic water can originate from various mining activities such as open mines, waste rock processing units, rock dumping sites, tailing waste processing, and material storage or stockpile locations. The water produced from coal mining is characterized by yellow, reddish-brown, and sometimes white colors.

The formation of acid mine drainage (AMD) begins with the presence of sulfide minerals contained in mined rocks. When these rocks are exposed, they react with oxygen and water, specifically, the oxidation of pyrite (FeS2), producing iron ions, sulfate, and other acidic substances that lead to acidic conditions. The reaction between iron, air, and water can produce sulfuric acid and iron hydroxide deposits, which are evident as yellowish deposits in the surrounding environment. This is an illustration of iron hydroxide, commonly known as "yellowboy." Generally, the formation of AMD is triggered by reactions in pyrite that produce hydrogen ions, which, when reacting with negative ions, form acid (Kamarullah et al., 2022).

The processes from the onset of mining activities, starting from exploration, require planning stages to calculate and predict the volume of AMD produced. This is crucial because the acidic nature of the AMD can pose environmental challenges for the exploiting companies. The AMD generated is not only from coal washing processes but also from the exposure of rock layers which can enhance the acidity in the environment, impacting water and soil quality. Therefore, it's vital to know and calculate the potential for AMD to develop preventive measures and management plans.

Efforts to control the conditions of AMD are crucial throughout the mining activities and even after their conclusion. This is because AMD can degrade the quality of water, both surface and groundwater. If it directly flows into rivers, it can have adverse effects on communities living around the river flow and can disturb aquatic and terrestrial biota (Hidayat, 2017).

According to Hidayat (2017), AMD formed at mining sites can negatively impact the environment. Some of the negative impacts include:

1. Effects on the nearby population: While the impact on residents living around mining areas is not usually immediate, as AMD flowing into rivers typically undergoes neutralization processes and its conditions (like turbidity, temperature, and pH) are monitored daily to stay within safe limits. However, if contamination occurs, aquatic life can be disrupted; for instance, fish can die, causing the nearby population to lose their livelihood.
2. Effects on aquatic biota: Negative impacts can affect aquatic biota, leading to alterations in the aquatic environment and a shift in biodiversity, including benthos and plankton. The presence of benthos in water indicates water quality. In healthy and fertile waters, there's an abundance of benthos, but in polluted and infertile waters, benthos struggles to survive.
3. Effects on surface water quality: The oxidation of pyrite that leads to the formation of AMD is one of the reasons for the decline in surface water quality. Indicators of this decline include increased dissolved solids, decreased pH, and elevated iron, sulfate, and manganese content in the water.
4. Effects on groundwater quality: The availability of nutrients in the soil is a factor for plant growth. Acidic soils contain a high concentration of heavy metals like copper, iron, and zinc, which are micronutrients. The excess of these nutrients can lead to plant poisoning, evidenced by root rot, causing the plant to wilt and eventually die.

*Environmental Quality Standards*

Wastewater from coal mining, also referred to as coal business wastewater, encompasses water produced from mining activities as well as from coal washing/processing. The term "wastewater quality standards" denotes the acceptable limits or standard concentrations of pollutants, including the overall pollutant elements, in the wastewater that is produced and meant to be discharged or released into surface waters (Indonesian Ministry of Environment’s Decision, 2003). At PT. TCM, the acid mine water, a form of coal waste, has an average pH of 3.2. This indicates non-compliance with the environmental quality standards referenced in Table 1.

**Table 1.** Wastewater Quality Standards for Coal Mining

| Parameter | Unit | Maximum Rate |
|---|---|---|
| pH | | 6-9 |
| Suspended residue | mg/l | 400 |
| Iron (Fe) Total | mg/l | 7 |
| Manganese (Mn) Total | mg/l | 4 |

Source: Indonesian Ministry of Environment’s Decision 2003 No. 113

The results of achieving pH for TCM type Quicklime at a price at 2,200,000.00/ton, with different weight variations at the start of the research can be seen in Table 2 and Figure 1.

**Table 2.** Price, Weight and achievement pH Quicklime TCM

| Weight (g) | pH Gain | Price (IDR) 2.200.000,00/pH Gain (Q) | Q*weight |
|---|---|---|---|
| 10 | 1,23 | 1,788,617.89 | 17,886,178.86 |
| 15 | 1,63 | 1,349,693.25 | 20,245,398.77 |
| 20 | 2,09 | 1,052,631.58 | 21,052,631.58 |
| 25 | 2,25 | 977,777.78 | 24,444,444.44 |
| 30 | 2,69 | 817,843.87 | 24,535,315.99 |
| 40 | 3,47 | 634,005.76 | 25,360,230.55 |
| 45 | 3,82 | 575,916.23 | 25,916,230.37 |

The comparison of Quicklime prices from TCM sources currently used for each pH achievement can be seen on the graph, where the additional cost is directly proportional to the increase in the quantity of Quicklime currently used. Based on the graph, to achieve acid mine water quality that meets quality standards, 45 grams of quicklime per liter of water are needed. So the cost needed to carry out the process of handling waste acid water at PT TCM using Quicklime per month is approximately Rp. 25,916,230.37.

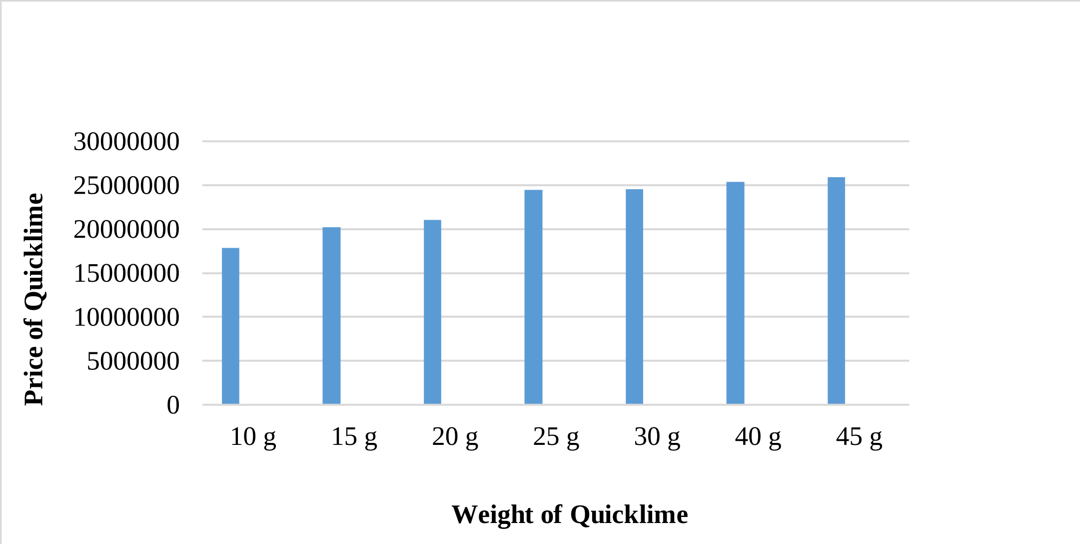


**Figure 1.** Graphic of Quicklime price/pH gain Calculated with weight

*Ishikawa Diagrams*

From the results of observations and data collection carried out on employees, the causes and consequences of the low quality of Quicklime currently used at PT. TCM are obtained can be seen in Figure 2.

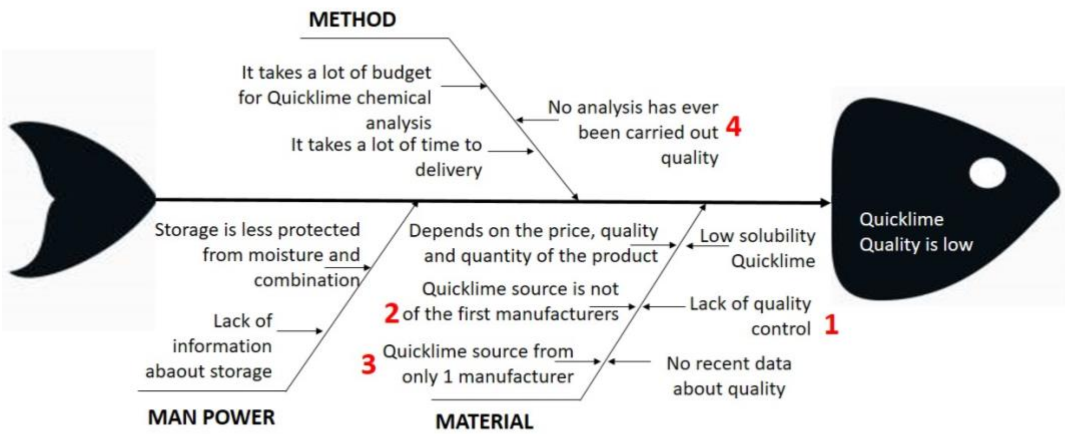


**Figure 2**. Causes and consequences of the low quality of Quicklime

After analysis, the root cause of the problem was found which was thought to be the cause of the low quality of the quicklime used so far, including:

a. Quicklime lack of quality control. This is predicted to be one of the causes of the quicklime used by PT. TCM in efforts to handle acid mine drainage at this time being less efficient because it does not know the exact quantity of quicklime used or the effect of reducing the resulting pH.
b. Source of quicklime not from the first producer. The quicklime that is provided is not sourced from the first producer, so it requires quite a long time for delivery due to the length of the distribution channel and the effect on the absorption of the acid mine drainage produced.
c. Quicklime only comes from one manufacturer, so there is no comparison. Quicklime only comes from one producer. Therefore, no comparison can be made both in terms of price and quality.
d. The quality analysis of Quicklime has never been conducted. The use of quicklime has never been chemically analyzed because of the relatively expensive cost of analysis. Therefore, by carrying out quality control independently, it is expected to be possible to obtain quicklime quality data while at the same time saving costs for handling acid mine drainage.

*Simple Regression Analysis*

The results of a simple regression analysis performed to test the quality of quicklime obtained the following results:

a. Lack of quality control from Quicklime

In order to control the quality of the type of quicklime used, a test was carried out to calculate the weight of the added quicklime and the resulting effect on achieving the pH of acid mine water in the first hour of addition. So the result obtained is that there is a positive correlation and a strong relationship between the two factors, as shown by the correlation coefficient r : 0.9978. The higher the weight of quicklime added, the higher the resulting pH.

| X Weight of Quicklim (g) | Y pH Gain |
|---|---|
| 10 | 1,23 |
| 15 | 1,63 |
| 20 | 2,09 |
| 25 | 2,25 |
| 30 | 2,69 |
| 40 | 3,47 |
| 45 | 3,82 |

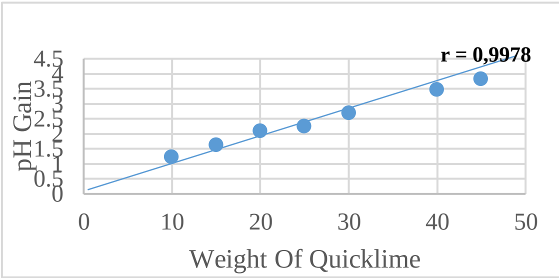


**Figure 3.** Relationship Between Ph Achievement and Quicklime Weight

b. Quicklime supplier is not from the first manufacturer.

The factor of the quicklime supplier not being from the original manufacturer is predicted to be one of the causes of the low quality of quicklime. This is evidenced by testing the duration of quicklime delivery due to the distribution chain and its influence on the absorption of acid mine water in the field. The obtained results show a positive correlation and a strong relationship between the two factors, with a correlation coefficient value of r = 0.9835. This means that the longer the quicklime delivery takes, the higher the absorption of acid mine water produced.

| **X water absorption (%)** | **Y Time (hours)** |
|---|---|
| 0 | 0 |
| 1,04 | 12 |
| 2,11 | 24 |
| 2,94 | 36 |
| 3,50 | 48 |
| 4,06 | 60 |
| 4,42 | 72 |

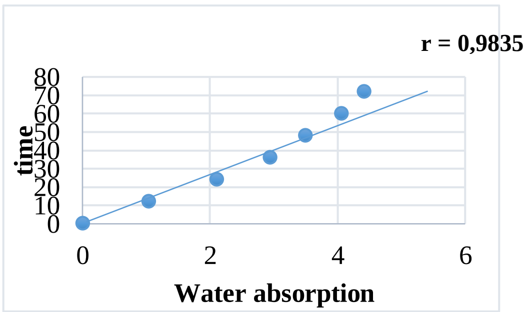


**Figure 4**. The Relationship Between Water Delivery and Absorption Time

c. The source of quicklime is only from one manufacturer, so there is no comparison available

The supplied quicklime has only been sourced from one manufacturer all this time. This can influence the quality of the quicklime used, as there are no alternative producers for comparison. This is evidenced by the high costs that are directly proportional to the weight of quicklime used for acid mine water treatment. It demonstrates a positive correlation and a strong relationship, with a correlation coefficient of r = 0.8328.

| X<br>pH Gain | Y<br>Price of quicklime (IDR) |
|---|---|
| 1,23 | 17,886,178.86 |
| 1,63 | 20,245,398.77 |
| 2,09 | 21,052,631.58 |
| 2,25 | 24,444,444.44 |
| 2,69 | 24,535,315.99 |
| 3,47 | 25,360,230.55 |
| 3,82 | 25,916,230.37 |

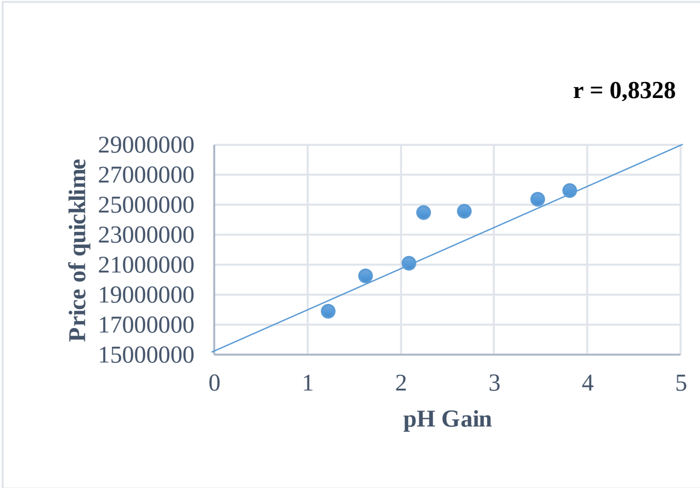


**Figure 5**. Graph of The Relationship Between Quicklime Price and Ph Achievement

d. The quality analysis of Quicklime has never been conducted

To accurately determine the quality of quicklime, periodic chemical analysis is necessary. This has not been done due to the high cost of analysis that needs to be covered. Based on the research findings, it was discovered that the cost of conducting chemical analysis is directly proportional to the examination parameters of quicklime. In other words, the more parameters that are analyzed, the higher the cost incurred. This is indicated by a positive correlation and a strong relationship between the number of analysis parameters and the required cost, as demonstrated by a correlation coefficient of r = 0.9273.

| X<br>The number of parameter | Y<br>Cost of analysis (IDR) |
|---|---|
| 1 | 250.000.00 |
| 2 | 500.000.000 |
| 4 | 750.000.000 |
| 5 | 850.000.000 |
| 6 | 1.000.000.000 |
| 7 | 1.100.000.000 |
| 11 | 1.300.000.000 |

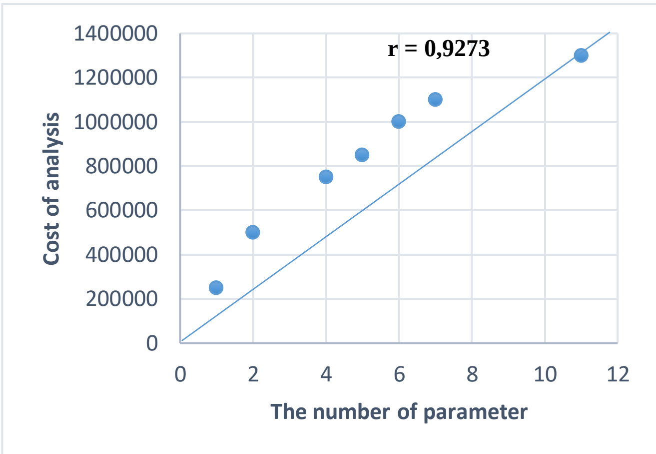


**Figure 6.** Graph of The Relationship Between Analysis Cost and The Number Of Analysis Parameters

*Discussions*

From the issues that are the dominant factors contributing to the low quality of quicklime, the results indicate that all four factors have a positive correlation and a strong relationship.

**Table. 3.** Dominant factor

| No | Dominant Factor | r | $r^2$ | % | Degree |
|---|---|---|---|---|---|
| 1 | Lack of quality control | 0,9978 | 0,9956 | 26,67 | 96 |
| 2 | Source of quicklime not from the first producer | 0,9835 | 0,9673 | 26,29 | 95 |
| 3 | Source of quicklime only from 1 producer | 0,8328 | 0,6936 | 22,26 | 80 |
| 4 | The analysis of actual quicklime quality has never used to follow up the chemical analysis result | 0,9273 | 0,8599 | 24,78 | 89 |
| | Total | 3,7414 | 3,5163 | 100,00 | 360 |

Based on the results of testing the quality of acid mine water using four different types of quicklime from various sources and their ability to increase the pH of acid mine wastewater, the following data was obtained Table 4. The highest increase in pH is demonstrated by the Quicklime sources IMM and MKS. Meanwhile, the lowest quicklime weight with the best quality is shown by the source from MKS, which increases the pH variance by 363.41%.

**Table 4**. The relationship between the source of quicklime and pH variance

| pH | JBG | TCM | IMM | MKS |
|---|---|---|---|---|
| Start | 3,24 | 3,23 | 3,20 | 3,19 |
| End of first hour | 4,44 | 4,46 | 8,03 | 7,66 |
| variant | 1,20 | 1,23 | 4,83 | 4,47 |
| Quicklime Weight (g) | | 45 | | 10 |

*The comparison of Quicklime usage weight before and after implementation*

The implementation results demonstrate that quicklime from the new source, MKS, shows greater efficiency compared to the previously used quicklime source, TCM. With a reduction in weight from 45 g/L to 10 g/L, it was able to increase the pH to meet the standard quality for acid mine water. This successful change also led to a 350% reduction in quicklime usage.

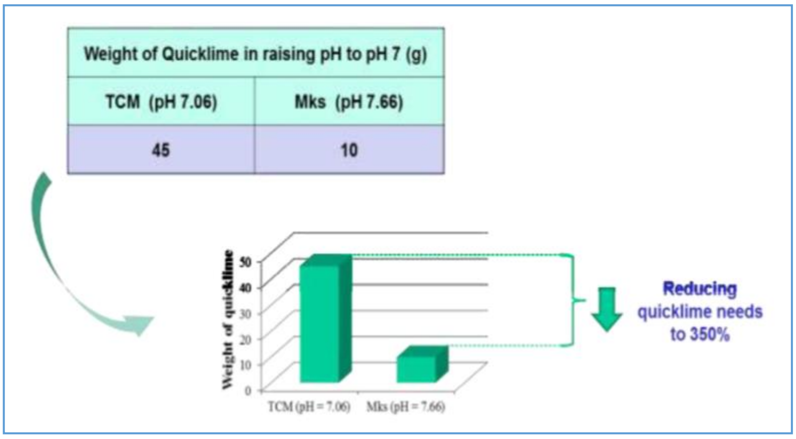


**Figure 7.** The Comparison of Quicklime Usage Weight With The New Source

*The comparison of pH achievement of Quicklime before and after implementation*

The implementation results yielded data indicating that the source of quicklime from MKS exhibited the best quality among the tested sources, as it was able to increase the pH variance by 363.41%.

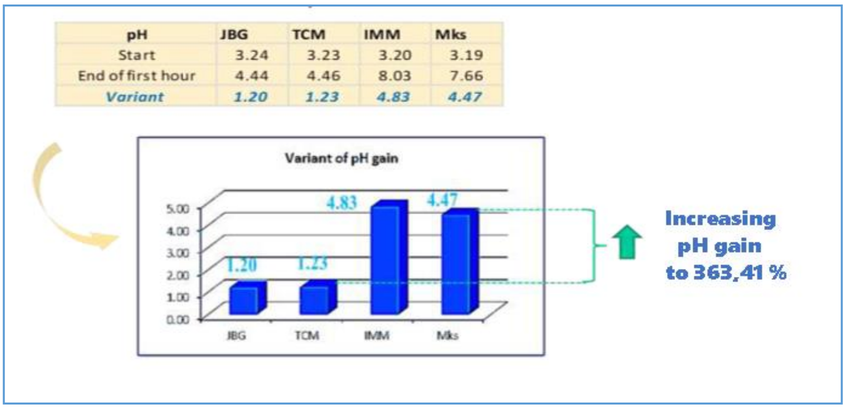


**Figure 8**. The comparison of pH achievement of quicklime from various sources

*The comparison of Quicklime prices before and after implementation*

The results of the implementation show that Quicklime from the MKS source demonstrates the best quality with the lowest price/pH gain at Rp. 281,879. This is advantageous for the company as it is able to reduce the cost of using Quicklime by 535%.

| QUICK LIME PRICE COMPARISON | JBG | TCM | IMM | Mks |
|---|---|---|---|---|
| IDR/ton | 1,150,000.00 | 2,200,000.00 | 2,000,000.00 | 1,260,000.00 |
| pH variant at end of first hour | 1.20 | 1.23 | 4.83 | 4.47 |
| Price/pH gain | 958,333 | 1,788,618 | 414,079 | 281,879 |
| Divide by 281,879 | 3.40 | 6.35 | 1.47 | 1.00 |

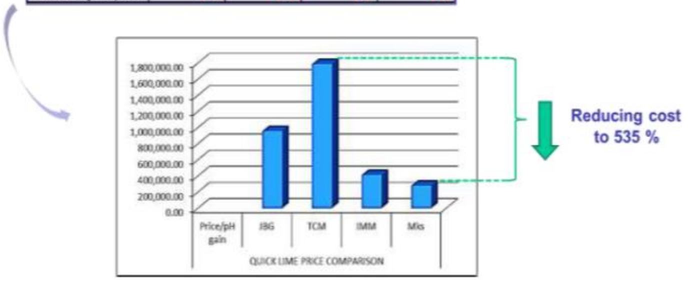


**Figure 9.** The Comparison of Quicklime Prices From Various Sources

*The comparison of chemical analysis costs with 3 parameters and the analysis conducted independently*

From the Figure 10, it is evident that conducting quality control analysis on quicklime using 3 parameters independently provides significant quality improvement and reduces chemical analysis costs by 15.85% compared to the cost required for laboratory chemical analysis

| Number of sample | cost (IDR) Analysis of Quicklime | |
|---|---|---|
| | Chemical (+tax 10 %) | Actual Quality |
| 1 | 1,430,000.00 | 3,610,000.00 |
| 2 | 1,430,000.00 | - |
| 3 | 1,430,000.00 | - |
| Total | 4,290,000.00 | 3,610,000.00 |

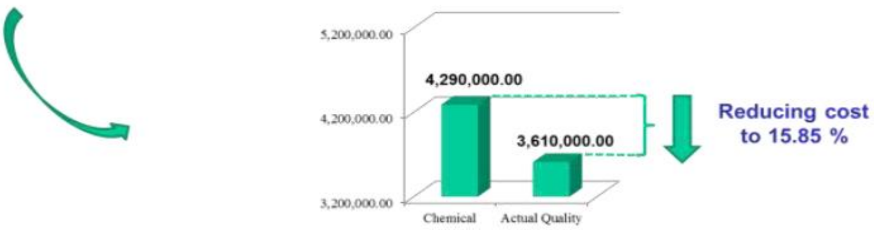


**Figure 10.** The Comparison Of Chemical Analysis Costs With The Number Of Analysis Parameters

## Conclusions

From the research results obtained, the following conclusions can be drawn:

a. The initiatives taken in this study to enhance the quality of quicklime—namely, implementing quality control, seeking alternative producers, and independently analyzing quicklime quality—had a significant influence on the quality of quicklime used in treating acid wastewater at PT. TCM.
b. Through these quality improvement efforts for quicklime, a more efficient new source of quicklime (MKS) was discovered, bringing about the following positive impacts for PT. TCM:
   - A reduction in quicklime requirements from 45 g/L to 10 g/L, indicating a decrease in quicklime needs by 350%.
   - An improvement in Quicklime quality, as seen in the increase in pH variance from 1.23 to 4.47, resulting in a pH enhancement by 363.41%.
   - A cost reduction in the use of quicklime from Rp.1,788,618 to Rp. 218,879, marking a decrease in expenses by 535%.
   - A 15.85% decrease in the costs associated with chemical analyses of quicklime, from Rp. 4,290,000 to Rp. 3,610,000, due to the analysis being conducted independently.

*Limitations of the Study*

The study primarily focuses on the quality of quicklime in treating acid wastewater at PT. TCM. The outcomes might not be generalizable to other mining entities or regions with different geological or operational characteristics. This research predominantly relied on quality control analyses using three independent parameters. This may not cover the full spectrum of variables affecting quicklime quality. The cost savings are calculated based on the data from PT. TCM and the specific parameters studied. Fluctuations in prices, market dynamics, or other external economic factors could affect the financial implications presented. The discovery of a more efficient source of quicklime (MKS) has shown significant results for PT. TCM. However, the availability, consistency, and scalability of sourcing from MKS haven't been extensively studied.

*Suggestions for Future Research*

Investigate the application of the findings from PT. TCM to other mining companies in different regions to test the generalizability of the findings. Explore additional parameters for quality control analysis of quicklime beyond the three used in this research to get a more comprehensive understanding of the factors influencing quality. A time-series analysis to observe the long-term impact and sustainability of using the MKS source for quicklime and its implications for cost, quality, and environmental impacts. Compare the efficiency and cost-effectiveness of different quicklime sources other than MKS to ensure diverse sourcing and risk mitigation. Given the importance of sustainability in mining operations, future research could delve into the environmental impact of the reduced use of quicklime and the newly discovered source (MKS) in the broader ecosystem.

*Strengths and Weaknesses*

The strengths of this research are using quantitative and qualitative approach by three analysis tools, the topic of this research is real and fresh to answer the problem in mining company by implementation this result. The weaknesses of this research is not showing map of operational PT. TCM or the other mining company because these datas are confidential for the companies. This research also don’t explain the comparation pH level from some Quicklime suppliers that can make effective cost.

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