# The Use of Neutralised Acid Mine Drainage Sludge as a Potential Coagulant in Treating Municipal Wastewater

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***Abstract*—Acid mine drainage (AMD) is a major environmental threat attributed to its strong acidity and high metal content. Conventional treatment methods, such as lime neutralization, result in significant sludge generation, which presents disposal and handling challenges. This study evaluated the efficacy of utilizing AMD sludge as a coagulant for treating municipal wastewater from the Polokwane Wastewater Treatment Works. AMD from Khwezela Colliery was selectively precipitated using lime to recover metal hydroxides of iron and aluminium. Under optimized conditions (dosage of 0.3 g and a contact time of 35 minutes), AMD's pH was increased from 2.76 to 8.79, and metal hydroxide recovery was done at pH 3.89 and pH 7.09, respectively. The resulting metal hydroxides were characterized for surface and elemental characteristics, then later were acidified to produce coagulants, ferric sulphate, and aluminium sulphate. Under optimized dosages of 150 mg/L ferric sulphate and 40 mg/L aluminium sulphate, the coagulants removed 97.53% and 95.62% of phosphates, respectively, from the municipal wastewater. The results suggest that reusing AMD sludge eliminates disposal challenges, while using AMD-derived coagulants provides an effective alternative to commercial coagulants, as their application improved the quality of the treated municipal wastewater sample. The treated AMD water achieved a slightly alkaline pH, while the treated municipal wastewater had a reduced organic load, making both treated samples suitable for reuse in industrial applications.**

***Keywords*—Acid Mine Drainage, Coagulants, Lime Treatment, And Sludge.**

## I. Introduction

Global mining operations have been essential to the global economy due to employment creation and revenue generation from mining activities. However, the growth of mining operations has been highly disadvantaged by the generation of acid mine drainage, which is a significant environmental threat [1]. This is attributed to colliery and gold mine operations, which have become key sources of acid mine drainage generation that negatively impact nearby water resources upon release [2].

The generation of acid mine drainage is caused by the oxidation of sulphide-bearing compounds such as pyrite in the presence of water, atmospheric oxygen, and the biocatalytic activity of bacteria such as *Thiobacillus ferroxidans* [3]. Most notable sulphide minerals include pyrite, arsenopyrite, and pyrrhotite, with pyrite being the most common source of AMD generation worldwide [4]. The discharge of AMD to nearby water catchments results in water quality alteration and ecosystem disruption owing to its strongly acidic nature and high dissolved metal concentrations [5]. The impacts on water quality include discoloration of water, decreased pH, and high electrical conductivity, which affects aquatic life dependent on the water resource.

As a measure to counter the impacts of AMD, conventional active treatment methods such as neutralization, precipitation, adsorption, and membrane filtration have been largely employed to remediate AMD-contaminated water [6]. Among these methods, lime neutralization has been one of the most prominent AMD remediation methods due to its cost-effectiveness and abundance of lime reserves [7]. Its treatment mechanism is largely through pH adjustment, which also facilitates the precipitation of metals in AMD, resulting in treatment. The main drawback of lime neutralization is the generation of toxic sludge, which presents disposal and handling challenges [8].

In dealing with the disposal challenges associated with lime neutralization, there has been a growing interest in sludge beneficiation, which makes valuable use of the sludge. This is largely due to the presence of valuable precious metals in the sludge [9]. One of the growing explorations includes the reuse of the metal hydroxides in the sludge to generate AMD-derived coagulants, which can be used for municipal wastewater treatment [10]. This innovative approach is supported by the increase in dysfunctional wastewater treatment facilities discharging untreated effluents to the environment, which potentially causes pollution. Part of the affected countries affected by this crisis is South Africa, which reported 34% of its wastewater treatment facilities in a dysfunctional state in 2022 [11]. As a result, an immediate sustainable solution is required wherein AMD-derived coagulants can provide a low-cost, sustainable approach to treat municipal wastewater in low-income municipalities of South Africa.

Therefore, the overall aim and objectives of this study are to neutralize AMD using lime and make it suitable for environmental discharge. In addition, to recover ferric- and aluminium (III) hydroxide, which will then be used to generate

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coagulants to treat municipal wastewater. Thus, addressing the dual challenge of AMD sludge disposal and untreated municipal wastewater effluents finding their way to the environment.

## II. Materials And Methods

### A. Sampling And Sample Preservation

The raw AMD was collected from Khwezela Colliery using a 25 L high-density polyethylene plastic drum to which was refrigerated at 4˚C to prevent precipitation and oxidation of metal anions in the sample. Similarly, the municipal wastewater sample was sampled from the Polokwane Wastewater Treatment Works using high-density polyethylene bottles, which were also kept at 4˚C to maintain sample integrity. Lastly, triplicate samples were taken at the respective sampling points to ensure accuracy and reliability of the results.

### B. Sample Preparation

The lime precipitant was sieved through a 100 µm sieve before application to the raw AMD sample to ensure uniform distribution of lime particles. To prepare the AMD for ICP-MS analysis, the AMD was diluted by filtering 10 mL of AMD and diluting it with 90 mL of deionized water to give a dilution ratio of 1:10. This ensured the reduction of the metal concentration in the original sample while ensuring that the sample did not exceed the detection limits of the ICP-MS instrument.

### C. Characterization of AMD

A pH meter (ACCSEN) was used for pH and temperature determination of the treated and untreated AMD samples. Similarly, a multimeter (HACH HQ40D) was used to determine the electrical conductivity of the AMD samples. Both meters were calibrated using standard buffer solutions before measurement to ensure accuracy. The metal content was determined using the ICP-MS instrument with method ME-011.

### D. Characterization of the Polokwane Wastewater Sample

For the determination of all physicochemical parameters, all instruments were calibrated before measurement to ensure the accuracy and reliability of the obtained results. A pH meter (ACCSEN) and a multimeter (HACH HQ40D) were used for pH, temperature, and electrical conductivity determination, respectively. For phosphate, chemical oxygen demand (COD), and true color determination, an Iris Visible Spectrophotometer (HI801) was used. Lastly, for turbidity measurement, a turbidimeter (Lovibond TB300 IR) was used.

### E. AMD Neutralization

AMD neutralization was done in a two-step selective precipitation process to selectively recover ferric hydroxide at pH 3-4 and aluminium hydroxide at pH 6-7. For this step, 500 mL of AMD was poured into six 1000 mL beakers, in which lime was added in increments of 0.05-0.30 g to each beaker. The beaker contents were then stirred on a 4-paddle stirrer (Model 1924, Electronics, India) at a speed of 200 RPM for 35 minutes. The experiments were carried out in triplicate at standard temperature conditions. Following neutralization, the mixtures were filtered using a 0.45 µm filter membrane, and the wet filtered sludge was dried for 15 minutes at 105˚C in an oven. This was done to produce a dried neutralised AMD sludge that was to be used for coagulant preparation.

### F. Characterization of lime and metal hydroxides

The powdered samples (lime and metal hydroxides/neutralized AMD sludge) were characterized using Scanning Electron Microscopy coupled with Energy Dispersive X-ray for surface morphology and elemental composition examination, X-ray fluorescence for elemental composition and elemental percentage, and Fourier-transform infrared spectroscopy for functional group and chemical bond identification. Lastly, particle size distribution analysis was used to determine the variation in particle size of the powdered samples

### G. Coagulant Preparation

Coagulant preparation was done in a two-step process, namely acidification and mixing. Acidification was done by acidifying the metal hydroxides (neutralized AMD sludge), ferric hydroxide, and aluminium (III) hydroxide using 4M $H_2SO_4$ to produce coagulants ferric sulphate and aluminium (III) sulphate, respectively. This was done by dissolving both metal hydroxides into two separate 20 mL beakers containing sulphuric acid. Mixing was done by stirring the beaker contents at 220 RPM for 15 minutes using a magnetic stirrer to stabilize the obtained coagulants.

### H. Coagulant Application

For the coagulation treatment process, two triplicate sets of 1 L beakers were used for each coagulant, in which 300 mL of the Polokwane municipal wastewater was added to the beakers. For the 40 mg/L aluminium (III) sulphate coagulant, an optimized rapid mixing speed of 100 RPM for 1 minute and a slow mixing speed of 25 RPM for 25 minutes was used. For the 150 mg/L ferric sulphate coagulant, an optimized rapid mixing speed of 180 RPM for 2 minutes and a slow mixing speed of 40 RPM for 20 minutes was used. A standing time of 30 minutes was allowed for settling, and afterward, 100 mL of the supernatant was pipetted from the beaker for analysis to determine the effectiveness of the prepared coagulants.

### I. Data Analysis

The removal efficiency of metals from the AMD and the contaminant removal efficiency from the municipal wastewater sample were computed using the following equation:

$$\%\ Removal\ = \left(\frac{Co-Cf}{Co}\right) \times 100 \quad (1)$$

Where CO is the initial concentration and Cf is the final concentration of the metal/contaminant.

## III. Results And Discussions

### A. Characterization of raw samples

Physicochemical parameters of AMD and the municipal wastewater sample

Tables I and II revealed that the AMD sample was strongly acidic with a pH of 2.76, and the municipal wastewater was

nutrient-enriched and highly turbid. The parameters of the AMD showed significantly high TDS and electrical conductivity values, which indicate high dissolved contents of various metals and salts contained in the sample. The municipal wastewater sample contained high phosphate and COD contents, which indicated a high nutrient content in the wastewater sample. This showed that both samples required immediate treatment before their discharge to the environment and reuse for industrial purposes.

TABLE I: AMD PHYSICOCHEMICAL PARAMETERS

| Sample | pH | TDS (mg/L) | EC (µS/cm) | Temperature (˚C) |
|---|---|---|---|---|
| Raw AMD | 2.76 | 249.61 | 257.33 | 15.1 |

TABLE II: POLOKWANE MUNICIPAL WASTEWATER PHYSICOCHEMICAL PARAMETERS

| Parameters | Sample |
|---|---|
| | Municipal Wastewater |
| pH | 7.47 |
| EC (µS/cm) | 84.6 |
| TDS (mg/L) | 54.99 |
| Temperature (˚C) | 21.13 |
| COD (mg/L) | 310 |
| Turbidity (NTU) | 52.6 |
| Phosphate (mg/L) | 190 |
| True color (PCU) | 61 |

*B. Selective precipitation and treated AMD characterization*

Neutralization of raw AMD through selective precipitation

Fig. 1 shows the selective precipitation of the AMD using lime to recover ferric hydroxide and aluminium (III) hydroxide, respectively.

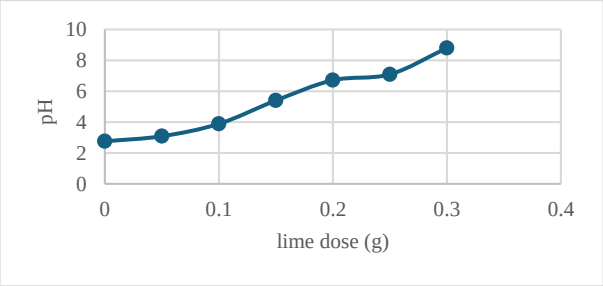


Fig. 1. The effect of various lime dosages on the pH of the AMD sample at room temperature conditions and a mixing speed of 200 rpm with a 35-minute contact time.

Fig.1 shows that the process of selective precipitation resulted in the pH adjustment of the AMD sample as the pH of the sample increased from a strongly acidic pH of 2.76 to a slightly alkaline pH range of 8.79 at a lime dosage of 0.30 g. The final pH of the sample of 8.79 was well within the Target Water Quality Range of pH 5.0-10.0, making the treated AMD suitable for reuse in industrial processes such as firefighting and irrigation, as suggested in the South African Water Quality Guidelines Volume 3. Additionally, the recovery of ferric hydroxide and aluminium hydroxide was done at pH 3.89 and pH 7.09, respectively, as both these pH values were within the pH 3-4 and pH 6-7 range for ferric hydroxide and aluminium (III) hydroxide precipitation. The recovery points of both metal hydroxides were largely influenced by the solubility of iron and aluminium ions, which combine with hydroxide (OH-) ions from the dissociation of lime upon precipitation. At a pH range of 3-4, the precipitation of $Fe^{3+}$ as $Fe(OH)_3$ occurs, as $Fe^{3+}$ is mostly soluble at this pH range, and at pH 6-7, $Al^{3+}$ is more soluble, causing it to precipitate as $Al(OH)_3$.

Table III Table 4.3 shows the metal concentration of the raw AMD and lime-treated AMD samples.

TABLE III: ANION AND METAL CONCENTRATIONS OF UNTREATED AND TREATED AMD

| Parameter | Sample ID | |
|---|---|---|
| | Raw AMD | Treated AMD |
| Sulphate (mg/L) | 1504.1 | 1443 |
| Calcium (mg/L) | 443.4 | 370.6 |
| Iron (mg/L) | 5.25 | ND |
| Aluminium (mg/L) | 0.38 | 0.01 |
| Zinc (mg/L) | 1.22 | 6.8 |
| Copper (mg/L) | 0.12 | 0.02 |

Key: ND- Not detected.

The ICP-MS results of the AMD samples revealed that the raw AMD sample contained high metal concentrations compared to the lime-treated AMD sample, as shown in Table III. The lime-treated sample showed that lime as a precipitant facilitated the reduction of metals as metal hydroxides of metals such as iron and aluminium from the metal-rich AMD sample. This is supported by the percentage reduction of 97.37%, 100%, and 83.33% for aluminium, iron, and copper, respectively. Similarly, the results also showed that the process of selective precipitation of iron and aluminium was effective as the concentration of iron was not detectable from a concentration of 5.25 mg/L, while aluminium was decreased from 0.38 mg/L to 0.01 mg/L. Therefore, suggesting that sufficient neutralized AMD sludge in the form of ferric hydroxide and aluminium hydroxide was successfully recovered at pH 3.89 and pH 7.09 to prepare the coagulants, which were subsequently used to treat the Polokwane municipal wastewater.

*C. Characterization of lime and neutralized AMD sludge*

SEM Results

Figs. 2 (a), (b), and (c) show the morphology of the lime and neutralized AMD sludge (metal hydroxide) particles under the scanning electron microscope.

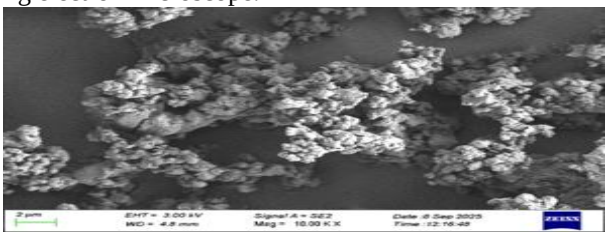

Fig. 2(a). Morphology of lime particles.

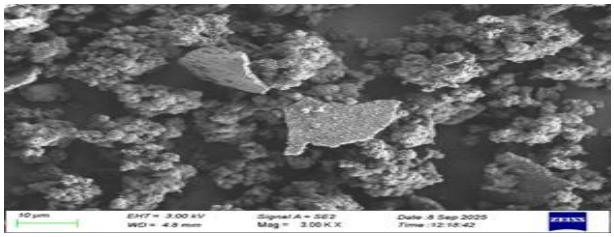

Fig. 2(b). Morphology of ferric hydroxide particles.

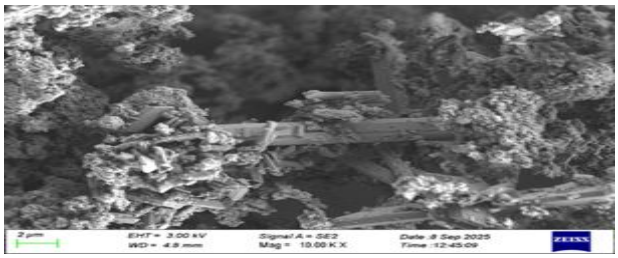

Fig. 2(c). Morphology of aluminium (III) hydroxide particles.

The lime particles showed uniform spherical shapes, which were consistent on all particles, as shown in Fig. 2(a). The morphology of ferric hydroxide in Fig. 2(b) revealed multiple spherical particles with tiny hollow perforations and large irregular angular shapes, thus exhibiting a large surface area for minute particle capture. Similarly, the morphology of aluminium hydroxide revealed particle shapes that were elongated, hexagonal-like shapes, which provided the necessary large surface area to capture colloidal particles from the municipal wastewater sample. However, from its morphology, various irregularly shaped particles were seen on image C in Fig. 2(c), which indicated the presence of other compound particles, such as lime, which was used as a precipitant in the experiment. Despite this, coagulation will not be affected as these metals can aid in capturing contaminants during coagulation treatment of wastewater.

**Energy Dispersive X-ray (EDX) Results**

The EDX spectra in Fig. 3 present the elemental composition of lime and the neutralized AMD sludge particles.

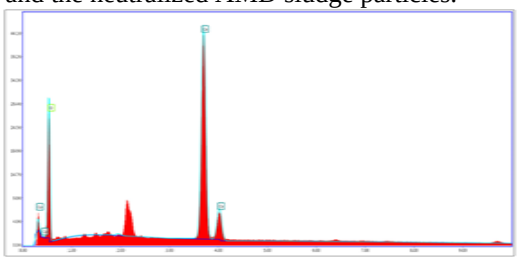

Fig. 3(a). EDX spectra of lime.

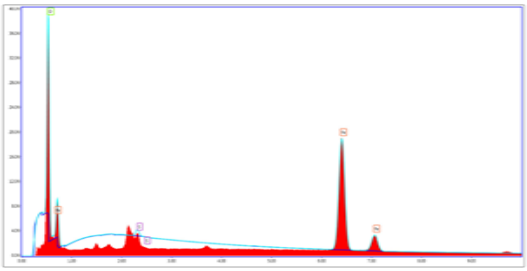

Fig. 3(b). EDX spectra of ferric hydroxide.

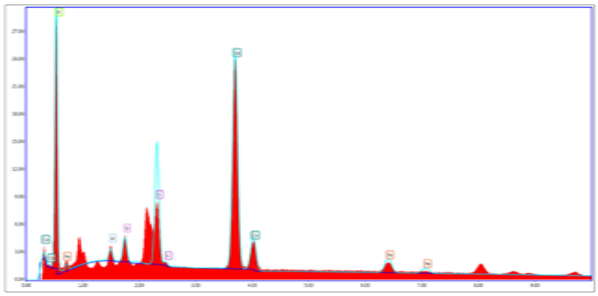

Fig. 3(c). EDX spectra of aluminium (III) hydroxide.

The results from the EDX analysis confirmed that the lime sample, which was used for AMD neutralization, was composed largely of calcium and oxygen by weight percentage, confirming that indeed calcium oxide was used throughout the selective precipitation/neutralization process. For ferric hydroxide, the results confirmed that it was successfully recovered from the AMD sample, as the bulk of the dried sludge was composed of 78.86% and 20.29% iron and oxygen, respectively. Similarly, the results confirmed that aluminium (III) hydroxide was also successfully recovered as the sludge was composed of 51.25% oxygen and 0.84% aluminium. However, large amounts of calcium (31.01%) from the lime precipitant were also present in the sludge along with metals such as $Fe^{2+}$ at 7.14%, which may have co-precipitated with $Al^{3+}$ in the AMD sample. Thus, suggesting that the AMD sample did not contain large amounts of aluminium (III) as compared to iron (III), as the latter was present in large quantities.

**XRF Results**

The XRF analysis results in Table IV show the elemental composition along with the percentage content of the lime, ferric hydroxide, and aluminium hydroxide particles.

TABLE IV: LIME, FERRIC HYDROXIDE, AND ALUMINIUM (III) HYDROXIDE ELEMENTAL COMPOSITION

| Element (%) | Lime | Ferric hydroxide | Aluminium (III) hydroxide |
|---|---|---|---|
| CaO | 69.285 | 0.68 | 40.694 |
| MgO | 0.94 | 0.744 | 1.064 |
| $Al_2O_3$ | 0.000 | 1.108 | 0.462 |
| $Fe_2O_3$ | 0.414 | 96.758 | 1.968 |
| S | 0.000 | 6.854 | 3.481 |
| Cu | 0.004 | 0.073 | 6.758 |
| Zn | 0.000 | 0.016 | 2.470 |

The XRF analysis of lime shown in Table IV showed that the lime sample contained calcium oxide with a percentage of 69.285% and along with impurities such as ferric oxide, magnesium oxide, and phosphorus pentoxide, which were present in low concentrations. The XRF analysis of ferric hydroxide, shown in Table IV, showed that the dried sludge was composed of ferric oxide, with the sludge being composed of 96.758% ferric oxide, indicating that ferric hydroxide was effectively recovered from the AMD sample. Similarly, aluminium (III) hydroxide was effectively recovered from the AMD sample as the dried sludge contained aluminium in the

form of aluminium oxide with a composition of 0.462% as shown in Table IV. The results also showed that sludge contained impurities such as calcium oxide, copper, ferric oxide, and zinc, which were of a higher composition than the recovered aluminium, which was targeted. Thus, proving that it was present in low amounts in the original AMD.

**FTIR Results**

Fig. 4 shows the FTIR spectra for the lime, ferric hydroxide, and aluminium (III) hydroxide samples, respectively.

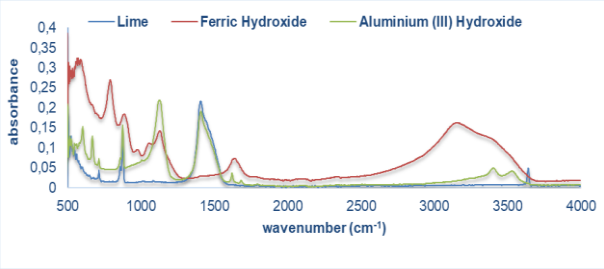


Fig. 4. FTIR spectra of the lime, ferric hydroxide, and aluminium (III) hydroxide, respectively.

The FTIR spectrum of lime in Fig. 4 showed O-H stretching around the 3500-4000 $cm^{-1}$ wavenumber, and different vibration modes of C-O between the 1000-1500 $cm^{-1}$ wavenumbers indicated that indeed lime was used in the study. The FTIR spectrum of iron (III) hydroxide showed O-H stretching and H-O-H bending around 3000-3500 $cm^{-1}$ and after 1500 $cm^{-1}$ wave number, respectively. Furthermore, sharp absorption bands at wavenumbers 500-1000 $cm^{-1}$ revealed the presence of Fe-O bond vibrations. The FTIR spectrum of aluminium hydroxide showed O-H stretching and bent vibrations of H-O-H, at wavenumbers around 3500 $cm^{-1}$ and 1600 $cm^{-1}$, respectively. Lastly, the broad peak along the 1000 $cm^{-1}$ wavenumber confirmed the bending of Al-O-H. Therefore, the FTIR spectra of both ferric hydroxide and aluminium (III) confirmed the presence of Fe-O and Al-O bonds in each sample, respectively, which showed that both metal hydroxides were successfully recovered from the AMD sample.

**Particle Size Distribution Results**

Fig.5 shows the particle diameter size of the lime, iron (III) hydroxide, and aluminium (III) hydroxide samples.

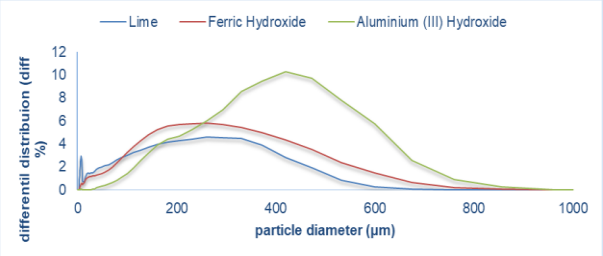


Fig. 5. Particle size distribution of the lime, iron (III) hydroxide, and aluminium (III) hydroxide particles.

From the Fig.5, the average particle size of the lime, iron hydroxide, and aluminium hydroxide particles was found to be 69.882 µm, 130.588 µm, and 277.560 µm, respectively. The obtained large particle sizes of both metal hydroxides were critical as they reflected the hydrolysis products of ferric sulphate and aluminium (III) sulphate upon application to the Polokwane municipal wastewater for treatment. As these metal hydroxides were large enough, they provided the necessary surface area to collide with negatively charged colloidal nanoparticles, which are excessively dispersed in the wastewater due to stronger Brownian motion, which improves coagulation performance.

*D. Coagulant preparation and application to the municipal wastewater sample*

Table V shows that both coagulants were strongly acidic and contained a high electrical conductivity content which was caused by the acidification process of the metal hydroxides using 4M sulphuric acid. Table VI showed that the application of both coagulants resulted in the reduction of parameters such as phosphates, COD, true color, and turbidity in the treated municipal wastewater sample.

TABLE V: PHYSICOCHEMICAL PROPERTIES OF THE COAGULANTS

| Coagulant Type | Concentration (mg/L) | pH | EC (µS/cm) | Temperature (˚C) |
|---|---|---|---|---|
| Ferric Sulphate | 150 | 2.27 | 1979 | 21.7 |
| Aluminium (III) Sulphate | 40 | 2.64 | 751 | 21.6 |

TABLE VI: FERRIC SULPHATE AND ALUMINIUM SULPHATE COAGULANT APPLICATION ONTO THE MUNICIPAL WASTEWATER

| Parameters | Samples | | |
|---|---|---|---|
| | Polokwane Municipal Wastewater | 150 mg/L Ferric Sulphate treated Wastewater | 40 mg/L Aluminium (III) Sulphate treated Wastewater |
| pH | 7.47 | 7.66 | 7.28 |
| Turbidity (NTU) | 52.6 | 9.82 | 12.73 |
| Phosphate (mg/L) | 190 | 4.7 | 8.33 |
| Temperature (˚C) | 21.13 | 21.27 | 21.4 |
| TDS (mg/L) | 54.99 | 61.4 | 55.17 |
| COD (mg/L) | 310 | 113.33 | 120 |
| EC (µS/cm) | 84.6 | 94.47 | 85.1 |
| True Color (PCU) | 61 | 8.67 | 40 |

*E. Coagulation treatment efficiency*

Table VII shows that both these AMD-derived coagulants were effective in treating the Polokwane municipal wastewater sample. This was seen as both coagulants were efficient in reducing the phosphate content with removal efficiencies of 97.53% and 95.62% for ferric sulphate and aluminium (III) sulphate, respectively. Similarly, the reduction of COD, which is a more accurate measure of the biodegradable and nonbiodegradable organic matter content of wastewater, was reduced by 63.44% and 61.23%, respectively, for ferric sulphate and aluminium sulphate. This was crucial as both these parameters are measures of the nutrient content of wastewater, and their reductions meant that the effluent was suitable for environmental discharge with a much lower potential to cause environmental damage by the Polokwane WWTW.

TABLE VII: TREATMENT EFFICIENCY OF THE FERRIC SULPHATE AND ALUMINIUM (III) SULPHATE COAGULANT IN TREATING THE POLOKWANE MUNICIPAL WASTEWATER.

| Removal efficiency (%) | Ferric Sulphate | Aluminium (III) Sulphate |
|---|---|---|
| Phosphate | 97.53% | 95.62% |
| Turbidity | 81.33% | 75.8% |
| True Color | 85.78% | 34.43% |
| COD | 63.44% | 61.23% |
| EC | -12.06% | -0.95% |
| TDS | -12.06% | -0.69% |

### *F. Physicochemical parameters of treated samples*

Table VIII shows the treated AMD and municipal wastewater samples.

TABLE VIII: PHYSICOCHEMICAL PARAMETERS OF THE TREATED SAMPLES

| Parameters | Samples | | | SAWQG Vol. 3 Industrial Use |
|---|---|---|---|---|
| | Treated AMD | 150 mg/L Ferric Sulphate treated W.W | 40 mg/L Aluminium (III) Sulphate treated W.W | Category 4 limits (TWQR) |
| pH | 8.79 | 7.66 | 7.28 | 5.0-10.0 |
| Turbidity (NTU) | - | 9.82 | 12.73 | - |
| Phosphate (mg/L) | - | 4.7 | 8.33 | - |
| Temperature (˚C) | 14.83 | 21.27 | 21.4 | - |
| TDS (mg/L) | 170.30 | 61.4 | 55.17 | 0-1600 |
| COD (mg/L) | - | 113.33 | 120 | 0-75 |
| EC (µS/cm) | 175.57 | 94.47 | 85.1 | 0-250 |
| True Color (PCU) | - | 8.67 | 40 | - |
| Sulphate (mg/L) | 1443 | - | - | 0-500 |

Key: W.W- Wastewater, SAWQG- South African Water Quality Guidelines, and TWQR- Target Water Quality Range.

Table VIII shows that the pH of both treated AMD and municipal wastewater samples was slightly alkaline, making them less corrosive. For both municipal wastewater samples, their overall turbidity, phosphate, and COD content were acceptable for environmental discharge, making them suitable for potential industrial and agricultural reuse. The effectiveness of the 150 mg/L ferric sulphate and 40 mg/L aluminium (III) sulphate was found to be largely due to the charge neutralization mechanism, which occurs when there is an adsorption of ions with an opposite charge to the coagulant particles. Hence, the reductions of turbidity, true color, COD, and phosphates were seen in Table VIII. Overall, these reductions indicate that AMD-derived coagulants can sustainably treat municipal wastewater to meet discharge and reuse standards.

## IV. CONCLUSION

This study aimed to evaluate the potential of neutralized AMD sludge as a coagulant in treating municipal wastewater to address the challenge of AMD sludge disposal and municipal wastewater treatment. Lime neutralization effectively increased AMD pH to alkaline levels, enabling efficient selective precipitation of $Fe(OH)_3$ and $Al(OH)_3$. These results demonstrate that lime can selectively recover iron and aluminium hydroxides from AMD, which can subsequently be repurposed as effective coagulants. This was seen with lime achieving effective metal hydroxides recovery with recovery efficiencies of approximately 100% and 97.37% for ferric hydroxide and aluminium (III) hydroxide, respectively.

The recovery of these metal hydroxides was essential as they provided the potential of being reused as coagulants used in the treatment of municipal wastewater. As such, both coagulants were effective in treating the municipal wastewater sample, as removal efficiencies of phosphates were 97.53% and 95.62% using ferric sulphate and aluminium sulphate, respectively. These also included key reductions of parameters such as turbidity, COD, and true color of the municipal wastewater sample. Thus, this study demonstrated that AMD, typically viewed as a pollutant, can be transformed into a valuable resource for wastewater treatment. Furthermore, this approach aligns with circular economy principles and offers a cost-effective solution for municipalities facing chemical procurement challenges.

## ACKNOWLEDGMENT

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