

Management of Acid Mine Drainage within a Wetland in the Tarkwa Area*

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Abstract

Acid Mine Drainage (AMD) is an environmental phenomenon that is being experienced by some surface mining companies in Ghana. Consequently, there is the need to generate information and expand local expertise base in handling this phenomenon. This work explored the sustainable anaerobic wetland mitigation method for the management of this phenomenon. Results of water analysis showed that the pH at the acidic effluent discharge area is 4.4 but then it increased gradually to pH of 7.5 in the wetland. The study identified a sulphate reducing bacterium (*Desulfovibrio desulfuricans*) in the wetland, whose activity produced OH⁻ ions that raised the pH of the acidic effluent resulting in the precipitation of heavy metals like iron, lead and nickel. Consequently, if the natural anaerobic remediation is engineered, the effluent from the AMD can be treated and discharged without causing any significant adverse impact to the geo-environment.

1 Introduction

AMD occurs when sulphide-bearing rock/material is exposed to water and air (Singer and Stumm, 1970). The phenomenon is a sustainable biochemical reaction, which produces acidic effluent that can mobilise heavy metals into the geo-environment. AMD is a serious environmental liability because the effluent is capable of contaminating surface water systems and aquifers among others (Warhurst, and Noronha, 2000).

Measures are always required to prevent or treat it by:

- i. Selective mining and storage of the sulphide material ((Durkin and Herrmann, 1994)
- ii. Isolation of the sulphide materials using covers such as soils, water, geo-materials etc (Filipek *et al.*, 1996)
- iii. Neutralisation of acid effluent using lime (Rose *et al.*, 1995)
- iv. Constructed wetlands (Gazea *et al.*, 1996).

Although lime is widely used to manage active AMD, the method is not sustainable after decommissioning. The concept nowadays is to develop mitigation methods that are sustainable after decommissioning, an example of which is a constructed wetland.

AMD is the most serious environmental impact caused by mining and is the industry's greatest environmentally related technical challenge (Warhurst and Noronha, 2000). Hence, there is the need to generate information and also expand local expertise base in handling AMD in Ghana. This work explored the sustainable anaerobic wetland mitigation process for the management of AMD in the Tarkwa area of Ghana by characterising the wetland, identifying the bacteria community and

studying biological and chemical activities that are enabling it mitigate AMD in the area.

2 Experimental Investigation

The AMD effluent from a waste dump in the study area discharges into a wetland (Fig. 1). The study was therefore designed to obtain some information on the wetland and the types of rock in the area and from the dump that has the potential of AMD generation. The following investigations were therefore carried out:

1. Microscopic examination of thin and polished sections of the rock types from the study area and the waste dump on the mine was carried out to ascertain AMD potential of the waste rocks. This was carried out using Lietz Laborlux 11 Pol microscope.
2. Water analysis; physicochemical properties of water samples were determined to check water quality and sulphate balance of the study area
3. Sediment Analysis;
 - Solid phase - XRD analysis to determine mineral phases in the sediments using Siemens D 500 Diffractometry and
 - Liquid phase - Biological analysis to identify bacteria species in the wetland using nutrient standard 11 and 16 (Karaivko *et al.*, 1977)

2.1 Sampling

2.1.1 Rock Sampling

Fresh rock samples (8) were taken from the working face of a pit in the study area for mineralogical study. The sampling was done after blasting had

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been carried out in the pit hence, to avoid picking transported material; a geological hammer was used to knock off the various rock samples from the parent rock. Eight thin and polished sections of the samples were prepared and studied under the microscope.

2.1.2 Water Sampling

A cleaned sample bottle was first rinsed with the water sample. The bottle was immersed to about 0.25 m and tilted against the direction of flow to collect the water. The samples were then kept in an ice chest and then sent to laboratory for determination of certain ions. The following parameters; temperature, pH, Electrical Conductivity (EC) and Turbidity were measured on the mine site using a portable water analysis kit.

2.1.3 Sediment Sampling

Soil sediment samples were taken by scooping about 100 g of the sediment together with the sediment water at about 0.3 m depth and then dried in the sun for some hours to remove all the moisture from it. The samples were prepared for XRD analysis. For the biological analysis, holes of about 0.3 m were dug in the sediment. Some few minutes was allowed for the sediment water to gradually percolate into the hole, after which the pH was read and the water was collected into LPE bottles. The sample points are shown in figure 1.

3 Results and Discussions

3.1 Mineralogy and AMD Potential

There are two types of sulphide bearing rocks that

Table 1 Modal % of Meta-Diorite

| MINERAL/SAMPLE NO. | PA-DH1 | PA-D4 | PA-DCF5 | PA-DCH3 |
|----------------------|--------|-------|---------|---------|
| Plagioclase | 15 | 20 | 12 | 16 |
| Amphibole + Chlorite | 40 | 35 | 35 | 30 |
| Quartz | 6 | 5 | 3 | 2 |
| Sericite | 15 | 15 | 16 | 20 |
| Fine quartz | 9 | 10 | 15 | 11 |
| Actinolite | - | - | 1 | - |
| Alkali Feldspar | - | - | - | 2 |
| Dolomite | - | - | 1 | - |
| Epidote | 2 | 2.5 | 3 | 10 |
| Calcite | 10 | 12 | 10 | 7 |
| Tourmalin | Trace | Trace | <1 | 0.5 |
| Pyrite | 1 | 0.5 | 3 | 0.5 |
| Magnetite | 1 | - | - | - |
| Gold | Trace | - | Trace | Trace |

Table 2 Modal % of Quartzite

| MINERAL/SAMPLE NO. | PA-QCH2 | PA-QCF6 | PA-QF7 | PA-Q8 |
|----------------------|---------|---------|--------|-------|
| Quartz | 60 | 50 | 50 | 55 |
| Plagioclase | 20 | 15 | 15 | 13 |
| Amphibole + Chlorite | 5 | 5 | 8 | 6 |
| Boitite | - | 1 | - | - |
| Sericite | 1 | 2 | 8 | 5 |
| Epidote | 10 | 15 | 10 | 5 |
| Tourmalin | 1 | 10 | 4 | 1 |
| Pyrite | 2 | 2 | 5 | 15 |
| Magnetite | 1 | - | - | - |
| Marcasite | Trace | Trace | - | - |

were identified in the study area namely: meta-diorite and quartzite (Table 1 and 2 respectively). Measurements made on both the thin and the polished section of the samples showed that the meta-diorite is made up of about 12 – 20 % Plagioclase, about 30 – 40 % Amphibole and about 2 – 6 % quartz as primary minerals and about 0.5 – 3 %

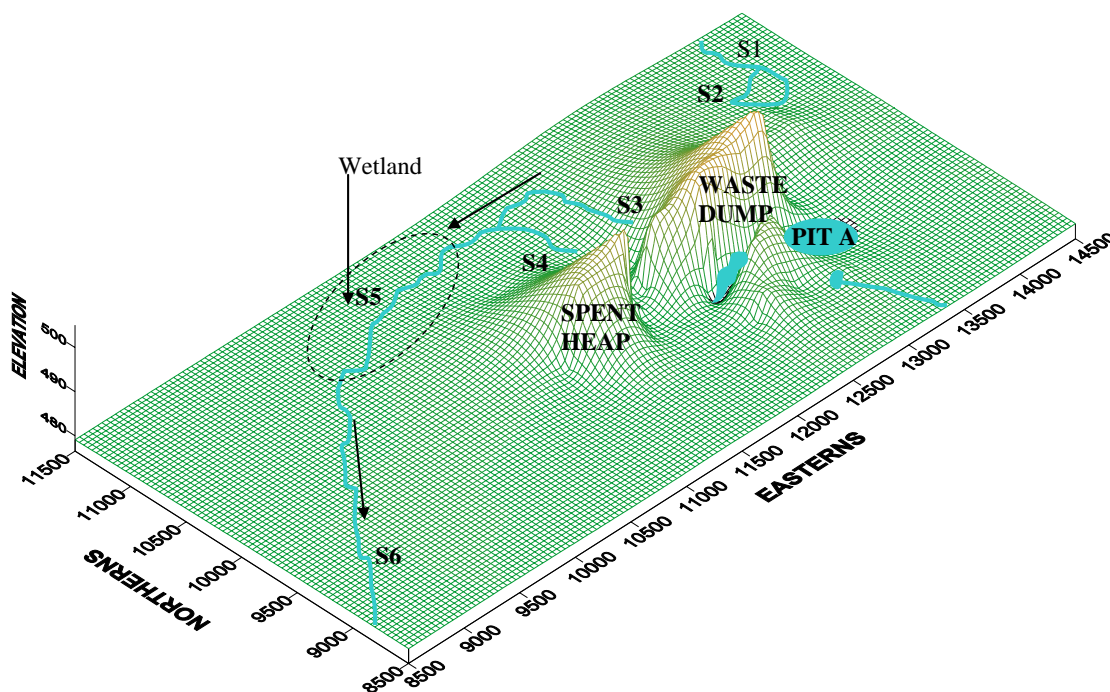


Fig. 1 A Surface Plot Showing Sample Points and Relief

pyrite, 7 – 12 % calcite, chlorite, sericite, fine quartz, alkali feldspar, actinolite, dolomite, epidote, tourmaline, magnetite and traces of gold constitute its secondary minerals. Figure 2 shows the photomicrograph of highly altered meta-diorite. The photomicrograph was specially prepared by joining two slides together to show the presence of euhedral pyrites and calcites in the meta-diorite. In the quartzite, the percentage determined for the primary minerals were about 50 – 60 % quartz, 13 – 20 % amphibole and about 5 – 8 % plagioclase. The secondary minerals include about 2 – 15 % pyrite, biotite, sericite, epidote, tourmaline, magnetite and traces of marcacite. The photomicrograph of quartzite is shown in Figure 3. The microscopic analysis revealed that the quartzite has no neutralisation material; in contrast, the meta-diorite has calcite (Fig. 3 and 2).

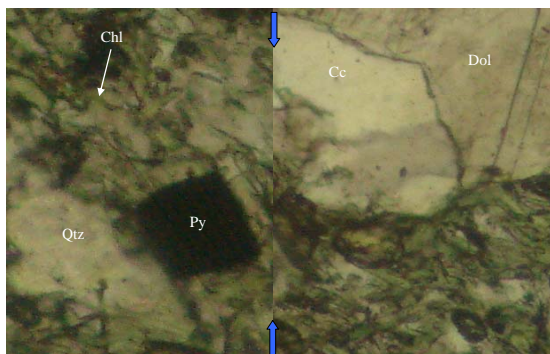


Fig. 2 Photomicrograph of Meta-Diorite (Sample PA-DCF5) Showing overprint of Euhedral Pyrite and the Relationship of some Metamorphic Minerals and Dolomite. Note Characteristic Twinkling of Dolomite replaced by Calcite. The Blue Arrows show the joint between the two slides (plane polarised light, x100)

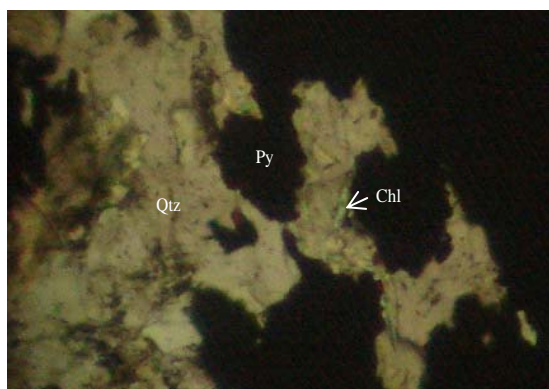


Fig. 3 Photomicrograph of Quartzite (Sample PA-Q8) Showing Overprints of a Cluster of Ore Minerals (plane polarised light, x1000)

The Neutralisation Potential of meta-diorite (NP) is amount of calcite in it which is given by the average percentage of calcite divided by the molecular weight of calcite

$$= 0.0975$$

Acid Generating Potential of meta-diorite (AGP) is given by the average percentage of pyrite divided by the molecular weight of pyrite

$$= 0.0104$$

$$\text{Acid Base Accounting} = \frac{NP}{AGP} = \frac{0.0975}{0.0104}$$

$$= 9.75$$

Since neither calcite nor any significant amounts of other neutralising material were found in the quartzite, its Neutralisation Potential (NP) is zero.

Acid Generating Potential of quartzite (AGP) however is given by the amount of pyrite in the quartzite thus average percentage of pyrite over molecular weight of pyrite

$$= 0.05$$

$$\text{Acid Base Accounting} = \frac{NP}{AGP} = 0.05$$

Therefore the ratio of neutralisation potential to acid generating potential (R) NP/AGP of the meta-diorite is 9.75 while that of the quartzite is zero. Normally if R is more than 3, then it is unlikely that the material will be acid generating. However if it is less than 3 the acid generating potential is likely (Warhurst and Noronha, 2000). It can therefore be inferred that the quartzite will be acid generating. The amount of quartzite in the waste dump is about 36 times more than the meta-diorite hence in a waste dump, the meta-diorite will offer a limited buffering capacity hence any waste dump consisting of similar rocks that is not environmentally designed will be acid generating for a long time.

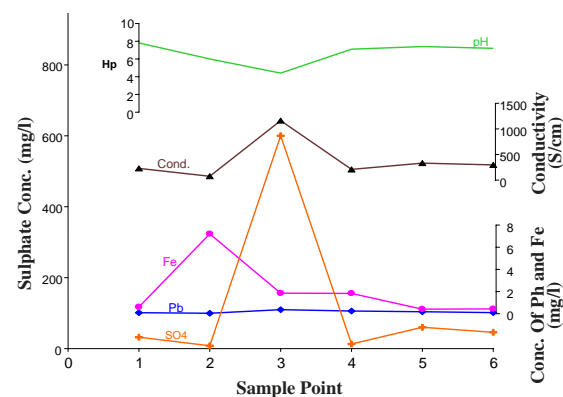


Fig. 4 Graph of Physico-Chemical Properties of Study Area

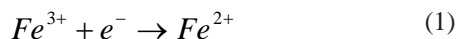
3.2 Characterisation of the Wetland

3.2.1 Water Analysis

Results of the water analysis are presented in Table 3 and Figure 4 which shows that the pH of water samples in the study area decreased gradually from a value of 7.8 (S1) to 4.4 within the environs of S3 and then increased gradually to pH of 7.2 (S6). It was also observed that the discharge of S3 was dark yellowish brown in colour. Hence, it can be inferred that although the pH around S3 is moderately acidic (3 - 5), the pH is finally restored to 7.4 about 1613.9 m down stream of S3. It is observed that the sulphate level at S3 is 600 mg/l while that of S4 was only 13 mg/l. Comparing the concentration of SO_4^{2-} at S3 and S4, the expected SO_4^{2-} concentration of S5 taking into account the effect of dilution should have been 248.26 mg/l (Figure 5) but after analysis, it was found to be 60 mg/l and this was hypothesized as due to the presence of sulphate reducing bacterium (*Desulfovibrio desulfuricans*) whose activity reduces SO_4^{2-} to S^{2-} in the wetland. This hypothesis was confirmed later during the bacteria analysis. Thus, there is a loss of 188.26 mg/l. It is interesting to note that there is a corresponding rise in sulphide level from 0.002 mg/l to 0.015 mg/l from S3 to S5, hence there is a process converting the sulphate to sulphide in this section of the wetland.

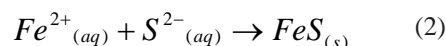
3.2.1 Sediment Analysis

The XRD analysis revealed that hematite is abundant in the sediment of S3 in contrast pyrrhotite was found in the sediments of S4 and S5. Formation of hematite indicates that the oxidation state of iron is in the oxidised (+3) state at S3 and because pyrrhotite is formed at S4 and beyond the iron is in the reduced (+2) state. Thus, it can be inferred that as the AMD effluent flowed through the wetland, iron has been reduced from +3 to +2 state as shown in equation 1.



Hence anaerobic conditions exist in the wetland. Furthermore, the biological analysis confirmed the presence of *Thiobacillus ferrooxidans* (sulphide leaching) bacterium at S3, while at S4 and S5 the sulphate-reducing bacterium *Desulfovibrio desulfuricans* was identified.

The biochemical activity of the sulphate-reducing bacterium takes place in anaerobic environments to produce sulphide ions and OH^{-} ions. Consequently the chemical analysis showed reduction in sulphate level and elevation in sulphide concentration and pH between S3 and S5. The sulphide ion reacts with Fe^{2+} to produce pyrrhotite (FeS) according to the reaction in equation 2.



While OH^{-} reacts with the acidic effluent to raise the pH. The FeS is chemically stable in anaerobic environment which is present in the wetland hence FeS will not be acid generating. These biological and chemical reactions are responsible for the natural mitigation of the AMD in the wetland. Therefore, by mimicking the biochemical reactions of this wetland the AMD problem of the waste dump can be sustainably mitigated.

Table 3 Results of some Water Quality Parameters

| SAMPLE POINT | S1 | S2 | S3 | S4 | S5 | S6 |
|--------------------|------|-------|-------|------|-------|-------|
| Temp. °C | 26.0 | 26.3 | 26.2 | 26.8 | 25.8 | 24.6 |
| EC (µS/cm) | 228 | 76 | 1160 | 208 | 332 | 296 |
| Turb. (NTU) | 8 | 55 | 7 | 5 | 3 | 265 |
| pH | 7.8 | 6.0 | 4.4 | 7.1 | 7.4 | 7.2 |
| Fe (mg/l) | 0.6 | 7.26 | 1.85 | 1.83 | 0.413 | 0.425 |
| SO_4^{2-} (mg/l) | 32 | 8 | 600 | 13 | 60 | 46 |
| Pb (mg/l) | 0.09 | 0.04 | 0.36 | 0.24 | 0.18 | 0.1 |
| Ni (mg/l) | 0.05 | 0.014 | 0.19 | 0.01 | 0.03 | <0.01 |
| S^{2-} (mg/l) | 0.01 | 0.053 | 0.002 | 0.05 | 0.015 | 0.013 |

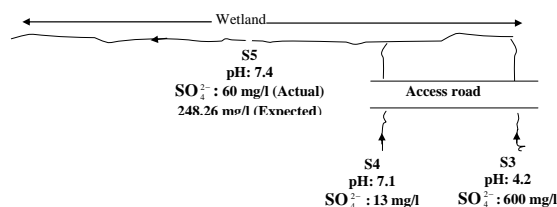


Fig. 5 Schematic Diagram Showing the Loss of Sulphate in the wetland

4 Conclusions

This study revealed that a wetland present in the study area contains a sulphate reducing bacteria *Desulfovibrio desulfuricans*, whose activity produces OH^{-} ions that raised the pH of the acidic effluent and also resulted in the precipitation of heavy metals in the effluent which mitigates AMD in the study area. It can therefore be deduced that if this natural process can be mimicked in an engineered anaerobic wetland, AMD can be sustainably managed as such the effluent from the wetland can be treated and discharged without causing any significant impact to the geo-environment.

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