Predicting the acid production potential of Mpumalanga coal mines

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Abstract

The paper focusses on predicting the acid production potential of Mpumalanga collieries in a 375 km² area. The area contains a number of surface mining activities as well as post-processing facilities. In order to assess the impact of these mining activities in the region, a survey was conducted on the acid producing capacity of the mines. Most of the mine sites investigated showed similar behaviour in respect to acid production potential. A representative site was selected which was further analysed by means of geochemical modelling and further sample analysis.

Keywords: Mpumalanga, coal fields, mining, impact, prediction, acid-base accounting

Introduction

During the last few decades' responsible mining has become a priority with certain mine houses due to environmental concerns. It has further developed in South Africa where mining companies are actively purifying mine water for domestic use, since South Africa is a water scarce country. The current paper deals with a preliminary investigation into the source water quality and prediction of mine water drainage quality over an extended timeframe. In order to complete the assessment, acid-base accounting was done in a specific area in Mpumalanga as well as a mineralogical and geochemical model of possible leachate production.

Methods

Acid-base accounting (ABA) is an initial classification procedure whereby the acid-neutralising potential and acid-generating potential of rock samples are determined, and the difference (Net Neutralising Potential – NNP) is calculated (Wilson 1994). The NNP, and/or the ratio of neutralising potential to acid-generation potential, is compared with a predetermined value, or set of values, to divide samples into categories that either require, or do not require further determinative kinetic test work. This static ABA does not provide information on the speed (kinetic rate) of acid generation (Mills 1998, Ziemkiewicz and Meek 1994). Rules and guidelines have been developed by mine regulatory and permitting agencies (e.g. Price 1997, Renton et al. 1988).

The following methods were used in this study: 1. Determination of reactive %S using hydrogen peroxide oxidation. 2. Neutralising potential using a sulphuric acid adaptation of the Sobek method (Sobek et al. 1978). 3. Calculation of acid : base ratios. 4. Determination of liberated elements during oxidation. Chemical samples

were analysed using a Perkin-Elmer 3000 DV-ICP. 5. Mineralogy of each sample using X-ray diffraction (XRD) and X-ray fluorscence (XRF) determination.

For this exercise 127 samples were taken for ABA testing, as indicated in Figure 1. This included 28 samples at Site 1 (waste rock), 44 at Site 2 (waste rock), 10 at Site 3 (waste rock), 28 at Site 4(waste rock), 10 at Site 5 (slurry ponds) and 7 at Site 7 (discard dumps). Additionally, 14 borehole samples and 8 final void samples were taken at specified acces points.

Figure 1 *Area of interest located in Mpumalanga province, South Africa, showing the sampling points.*

Results and Discussion

Overview of ABA data types obtained

In the procedure followed, the pH values of the pulverised samples are measured in water (start or initial pH) and after complete oxidation (final pH). Samples were deamed to be completely oxidized if no further reaction with peroxide was observed. This is the first indicator of the overall behaviour of the sample. High risk acid generators are those samples turning acidic upon oxidation. The initial and final pH values are plotted together with the overall difference between the acid potential and neutralisation potential in kg/tonne (NNP). By convention $CaCO_3$ is used rather than H_2SO_4 for expressing acid or neutralisation potential. If the NNP value is negative it means that there is no neutralisation potential and that acid generation will take place and vice versa (Figure 2).

To the far left on the graph the sample are already oxidised in the field and has a high acid potential. Closer to values of -50 NNP on the graph, samples have an alkaline initial pH but upon oxidation will turn acidic but will not produce as much

acid as the first mentioned. On the positive side of the scale, the pH upon oxidation (final pH) did not turn acidic and these samples contain a neutralisation potential with a lower likelihood of producing Acid Rock Drainage (ARD).
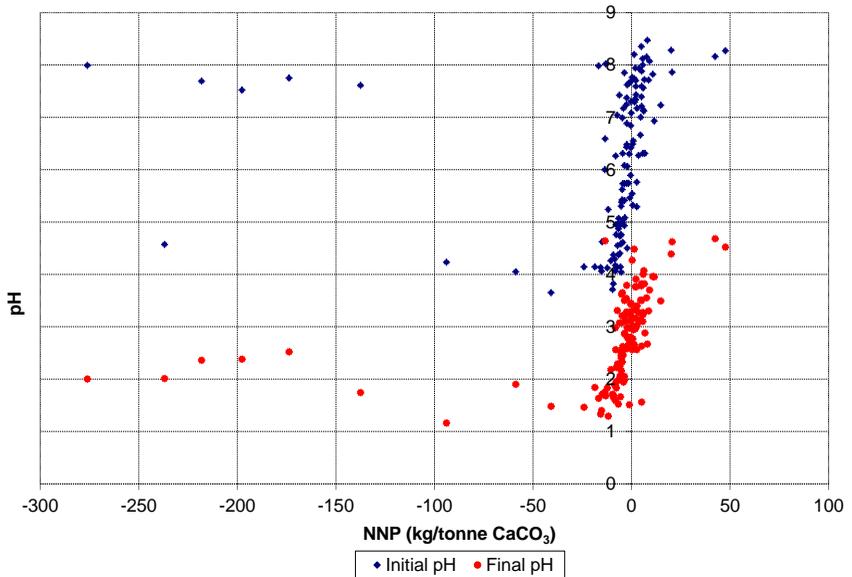
Figure 2 A NNP vs pH (initial and final) diagram (closed system) showing initial results for all samples.

Calculated Parameters from ABA and screening criteria. Based on the above tests, the following parameters can be calculated:

- Net Neutralising Potential (NNP) = Neutralising Potential (NP – kg/t $CaCO_3$) - Acid-Generating Potential (AP – kg/t $CaCO_3$), and Neutralising Potential Ratio (NPR) = NP/AP
- Details of the screening criteria for each type of test are given in publications such as Price and Errington (1998).

The most important criteria are as follows:

For NNP

- If NNP =NP-AP <0 - The sample has the potential to generate acid and
- If NNP =NP-AP >0 - The sample has the potential to neutralise produced acid

More specifically any sample with NNP<20 is potentially acid generating, and any sample with NNP > -20 might not generate acid.

There is a strongly defined "grey area" between -20 and = 20 kg/t $CaCO_3$, since the nature of static testing and the field variability makes it risky to assign potentially acid or non-acid generating properties to such samples.

For NPR the following guidelines are used for the classification of samples (Table 1).

Table 1: *Guidelines for ABA screening criteria (from Price and Errington 1998)*

ARD potential	NPR screening criteria	Comments
Likely	<1:1	Likely ARD generating
Possibly	1:1 - 2:1	Possibly ARD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
Low	2:1 - 4:1	Not potentially ARD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
None	>4:1	No further ARD testing required unless materials are to be used as a source of alkalinity

Open versus Closed Systems

It is important to differentiate between so called "**open**" and "**closed**" systems. The carbonate system is predominant in controlling the buffering intensity and neutralising capacity of natural waters, and represents a complex system involving the transfer of carbon among three phases: solid, liquid and gas. When $CO_2(g)$ is brought into contact with water, it will dissolve and form carbonic acid (H_2CO_3) until an equilibrium state is reached. Depending on the pH of the solution, the carbonic acid will tend to dissociate to hydrogen, bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions.

In an open system:

$FeS_2 + 2CaCO_3 + 3.75O_2 + 1.5H_2O \Leftrightarrow Fe(OH)_3 + 2SO_4^{2-} + 2Ca^{2+} + 2CO_2$ (exsolves into atmosphere)
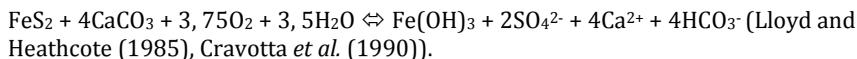
Acidity produced from 1 mole of FeS_2 (64 g sulphur) is neutralised by 2 moles of $CaCO_3$ (200 g) or 1 g sulphur: 3.125 g $CaCO_3$ (Brady *et al.* 1994).

In a closed system:

$FeS_2 + 2CaCO_3 + 3.75O_2 + 3.5H_2O \Leftrightarrow Fe(OH)_3 + 2SO_4^{2-} + 2Ca^{2+} + 2H_2CO_3$ (CO_2 dissolve in water)

H_2CO_3 reacts with carbonate in the following reaction: $H_2CO_3 + CaCO_3 \Leftrightarrow Ca^{2+} + 2HCO_3^-$

A second reaction depicting the maximum calcium carbonate requirements for acid neutralisation in a closed system may therefore be written as:

$FeS_2 + 4CaCO_3 + 3,75O_2 + 3,5H_2O \Leftrightarrow Fe(OH)_3 + 2SO_4^{2-} + 4Ca^{2+} + 4HCO_3^-$ (Lloyd and Heathcote (1985), Cravotta *et al.* (1990)).

In this reaction 1 mole of FeS_2 is neutralised by 4 moles of $CaCO_3$, which results in a mass ratio of 1 g pyrite: 6.25 g calcite. The application of the correct conceptual model is therefore of great importance in the interpretation of the results.

Acid Base Accounting

A summary of the results are displayed in Figure 2 and Figure 3. The overall interpretation from the graphs shows that acid rock drainage will occur in most samples upon oxidation.
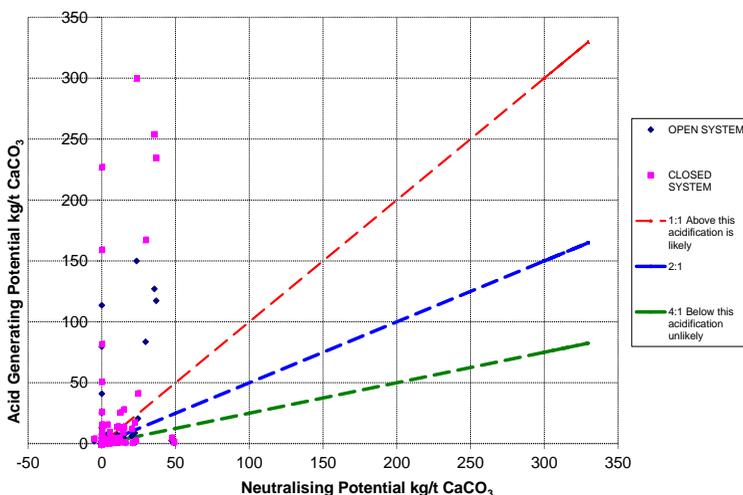

Figure 3 *AP vs NP for all samples tested.*

Mineralogy

At Site 1 two main mineralogical groups were identified. Firstly, a predominantly quartzitic and kaolinite rich system with traces of potassium feldspar. Secondly, a group was identified which contained mainly quartz and to a lesser extent kaolinite and potassium feldspar. The presence of buffering material such as calcite or dolomite is largely absent. Site 2 consists of quartz and kaolinite and minor components of potassium feldspar and gypsum. A second group can also be identified which consists predominantly of quartz and to a lesser extent kaolinite with traces of illite, potassium feldspar and gypsum. In the instance of Site 2 conversion of pyrite to depositional gypsum is already occurring. A further factor supporting this observation is the absence of buffering material such as calcite or dolomite from the mineralogical analysis. Site 3 consists of predominantly of quartz and kaolinite and minor components of potassium feldspar and illite. Site 4

has a similar composition to Site 3. The slurry mine area (Site 5) consists mainly of quartz and a minor component of kaolinite, which is followed to a lesser extent by lower concentration of gypsum, calcite and pyrite. In the instance of Site 5 the conversion of pyrite to depositional gypsum has occurred readily. The conversion of pyrite to sulphate containing species most likely will continue to occur with an initial buffering reaction taking place with the calcite to form more gypsum. The discard mine area (Site 6) consists of predominantly quartz and kaolinite and a minor component of gypsum. Trace amounts of calcite, potassium feldspar and illite is present in the dump. In the instance of the discard mine area conversion of pyrite to depositional gypsum has occurred readily. The conversion of pyrite to sulphate containing species most likely will occur with an initial buffering reaction taking place with the calcite to form gypsum.

Interpretation of single site data

A representative site was selected which could be used to illustrate the main problems that occur in the Mpumalanga coal mines. Site 2 was selected since it covers the most area and represents the bulk of the samples analysed in this report and will be discussed in the following paragraphs.

A geochemical model was constructed for Site 2. In order to model the chemical properties of the Site 2 an average mineralogical composition was prepared. The values are as follows: quartz 40 %, kaolinite 40 %, potassium veldspar 3 %, illite 10 %, pyrite 2 % and gypsum 8 %. Due to the abundance of pyrite in the average sample and the lack of buffering material, the initial modelling efforts showed that the pH would significantly drop. To illustrate this effect a solution which is in equilibrium with the mineralogy and infiltrated oxygen was exposed in a stepwise manner to the pyrite in the subsurface, after which it was allowed to leach from the heap into the surrounding area. Finally to investigate the effects on site, it was assumed that the oxygen rich water would come in direct contact with all the pyrite in the dump. Thus the hydrogeochemical model presented is the worst case scenario for this site.

The effect on the buffering capacity of the calcite mineral in the system is illustrated in Figure 4 and Figure 5. If it is assumed that all the pyrite reacts with the solution a final pH of 2.19 is obtained with a sulphate load of 17.83 ton/d.

It is clear from Figure 4 and Figure 5 that acid rock drainage will occur from this site and thus confirm the ABA results. In addition to this a high sulphate load would be observed with the addition of iron leaching into the environment as Fe^{+3} which would subsequently convert to $Fe(OH)_3$ in the surrounding environment.
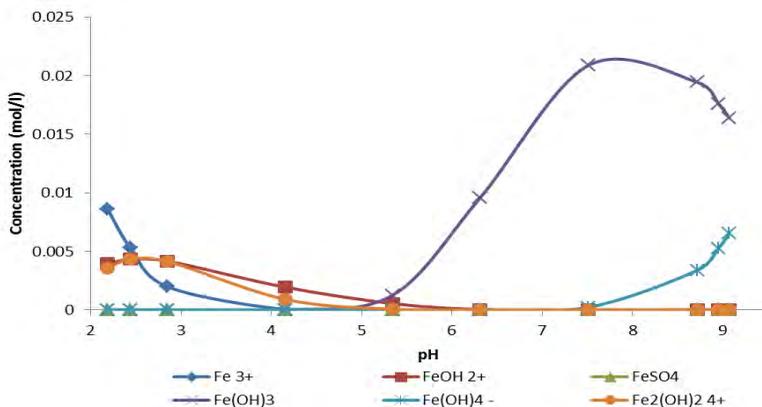
Figure 4 *Iron soluble species present in leachate at the Site 2.*
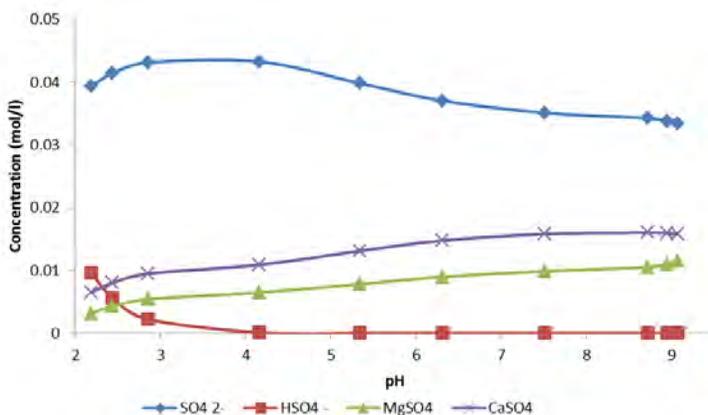
Figure 5 *Sulphate soluble species present in leachate at the Site 2*

Conclusions

In the current paper the acid producing potential of a coalfield located in the Mpumalanga area have been discussed. The data indicates that a significant portion of the sampled area will most likely produce low pH drainage water over the medium to long term. This observation was confirmed by geochemical modeling and illustrates the impact that these surface discard sites will have on water quality in the area.

Acknowledgements

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