Mitigating Acid and Metalliferous Drainage in the Asam-Asam Basin, South Kalimantan, Indonesia

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Research aims:
This research aimed to assess the acid and metalliferous drainage problems in the Asam-Asam coal basin. The project included:

- a case study of pit lake water chemistry
- knowledge transfer through in-country workshops
- the opportunity to collaborate with lead researchers in the field from Bandung Institute of Technology and Bengkulu University

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IM4DC
Action Research Report

International Mining for Development Centre

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The University of Queensland Australia
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Summary of Action Research Activity

Mitigating acid and metalliferous drainage in the Asam-Asam Basin, South Kalimantan, Indonesia

Acid and metalliferous drainage (AMD) is a major environmental problem in the coal mines of the Asam-Asam Basin, South Kalimantan, Indonesia. This project conducted by the Sustainable Minerals Institute in collaboration with Bandung Institute of Technology (ITB), aimed to assess the AMD issues by visiting the area, reviewing site specific environmental monitoring data and gathering information through on-site discussions and workshops.

The study found that there were three major areas that required further attention in order to mitigate the risks associated with AMD. These were:

1. the periodic overflow of acidic water from pit lakes and the lack of enough hydrological monitoring data or a water balance model, which has resulted in inefficient water treatment
2. uncertainties with regard to the classification of solid materials for acid generation potential, due to not measuring metal acidity by dissolution of Al and Fe minerals, which commonly add to proton acidity by pyrite oxidation
3. the interference of illegal miners through opportunistic and indiscriminatory mining practices which makes any catchment scale strategies for AMD management impossible.

The study concluded that there was not enough timely hydrological and geochemical monitoring data to effectively mitigate the risks from the pit lake acidic overflows. In addition, on a catchment scale, AMD management strategy requires co-operation with the illegal miners.

The report made the following recommendations for further studies to address the above issues for mitigating the risk of AMD either by at-source control or by treatment of the impacted waters:

1. a hydro-geochemical modelling study, including water balance modelling, based on timely water flow and water quality monitoring
2. a social study to better understand the drivers of illegal mining to enable the development of a catchment scale AMD management strategy involving local communities

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MITIGATING ACID AND METALLIFEROUS DRAINAGE IN THE ASAM-ASAM BASIN, SOUTH KALIMANTAN, INDONESIA

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MITIGATING ACID AND METALLIFEROUS DRAINAGE IN THE ASAM-ASAM BASIN, SOUTH KALIMANTAN, INDONESIA

EXECUTIVE SUMMARY

Acid and Metalliferous drainage (AMD) is a major environmental problem in the coal mines of Asam-Asam Basin, South Kalimantan, Indonesia. This IM4DC action research project, conducted by the Sustainable Minerals Institute in collaboration with Bandung Institute of Technology (ITB), aimed to assess the AMD issues by visiting the area, reviewing site specific environmental monitoring data and gathering information through on-site discussions and workshops.

The study found that there were three major areas that required further attention in order to mitigate the risks associated with AMD. These areas were: 1. the periodic overflow of acidic water from pit lakes and the lack of enough hydrological monitoring data and a water balance model which has resulted in inefficient water treatment; 2. uncertainties with regard to the classification of solid materials for acid generation potential, due to not measuring metal acidity by dissolution of Al and Fe minerals, which commonly add to proton acidity by pyrite oxidation; 3. the interference of illegal miners through opportunistic and indiscriminatory mining practices which makes any catchment scale strategies for AMD management impossible.

The study concluded that there was not enough timely hydrological and geochemical monitoring data to effectively mitigate the risks from the pit lake acidic overflows. In addition, and on a catchment scale, AMD management strategy requires co-operation with the illegal miners. The report made the following recommendations for further studies to address the above issues for mitigating the risk of AMD either by at-source control or by treatment of the impacted waters: 1. a hydro- geochemical modelling study, including water balance modelling, based on timely water flow and water quality monitoring; 2. a social study to better understand the drivers of illegal mining to evaluate the development of a catchment scale AMD management strategy involving local communities.

INTRODUCTION

Indonesia has experienced significant development of its mining industry since the late 1970s and is now considered as a global producer of tin, copper, nickel and thermal coal. As a consequence, environmental and social impacts of mining and mineral processing waste have also increased and Acid and Metalliferous Drainage (AMD) is currently considered the most important impact of mining activities in both coal and metal mining areas. In the last decade, there has been a growing interest in research and development on AMD management among mining companies, government and research organisations, to advance AMD characterisation, as well as prevention and remediation methods. This is particularly the case for medium- and small-scale mining operations who commonly, and in most cases inefficiently, simply use lime for AMD neutralisation without sufficient background studies or understanding of AMD processes.

This IM4DC action research aimed to provide a high-level assessment of the AMD problems in the Asam–Asam Basin, a relatively small but economically important coal basin located in the South Kalimantan Province of Indonesia. The project included knowledge transfer through in-country workshops and a case study of pit lake water chemistry. It provided an excellent opportunity to collaborate with lead researchers in the field from Bandung Institute of Technology and Bengkulu University.

We visited Professor Rudy Sayoga Gautama and his colleagues in the Bandung Institute of Technology (ITB) and discussed the environmental and social aspects of the study area as well as potential further collaborations. Following the research planning meetings, in April 2014 we travelled to PT Jorong Barutama Greston coal mine located in Jorong District, Province of South Kalimantan, accompanied by Prof Sayoga Gautama and Dr Ali Munawar from Bengkulu University (Figure 1). Following the field work and visit of a geochemical laboratory, we participated in a workshop to discuss specific issues on site.

Although the mine site was relatively small, compared to some of Australian operations, the AMD issues were significant. Our initial assessment showed there were three major aspects of mining in Asam-Asam area that require improvement, either by collecting appropriate monitoring data or by stakeholder consultation and engagement:

1. The mine pit lakes are major sources of AMD in the area, hence understanding geochemistry of the lakes would help to prevent and/or mitigate the AMD impacts on local streams;

2. More robust methods for geochemical characterisation of coal spoils could help to better predict AMD. Moreover, other potential solid sources of AMD including metal acidity from natural soils should be investigated;
3. Illegal or small scale mining activities not only create safety and human health issues, they hamper the mine AMD management plans and exacerbate the AMD issues through random and opportunistic mining. The illegal mining as such prevents the success of any catchment scale AMD management strategies.

Upon return from Indonesia, the AMD issues at PT Jorong were studied further using secondary data provided by the company and Indonesian research partners. Preliminary geochemical equilibrium modelling at UQ, using PhreeqC model, of a set of pit water quality data helped to better understand geochemical controls on water chemistry.

Illegal mining issues were discussed with Bernadetta Devi from the Centre for Social Responsibility in Mining (CSRM, UQ), and pit lake water balance issues were discussed with Dr Greg Kier from the Centre for Water in the Minerals Industry (CWiMI, UQ).

This report includes recommendations for further work at PT Jorong as a typical case study in the Asam-Asam Basin. Those recommendations will be used for the preparation of a proposal in collaboration with ITB for follow up studies targeted at AMD and illegal mining issues at PT Jorong.

Active pit

Old (background) and new rehabilitation sites

On site workshop

Plant nursery

M4E Pit Lake

Figure 1 PT Jorong Coal mine, Asam-Asam Basin, Kalimantan (April 2014)

RESULTS AND DICUSSION

Review of the study area

The Asam-Asam Basin is situated in SE Kalimantan, Borneo, along the southeast flanks of the Meratus Mountains (Appendix 1 and Figure 2). The elevation of the coalfields along the coast of the eastern Kalimantan is between 5 m to 300 m above sea level. The region has a tropical rainforest vegetation cover. Apart from the coal, gold and oil, agriculture, fishing and a commercial timber mill contribute to the economy of the area. The region has the second largest coal resources in Indonesia.

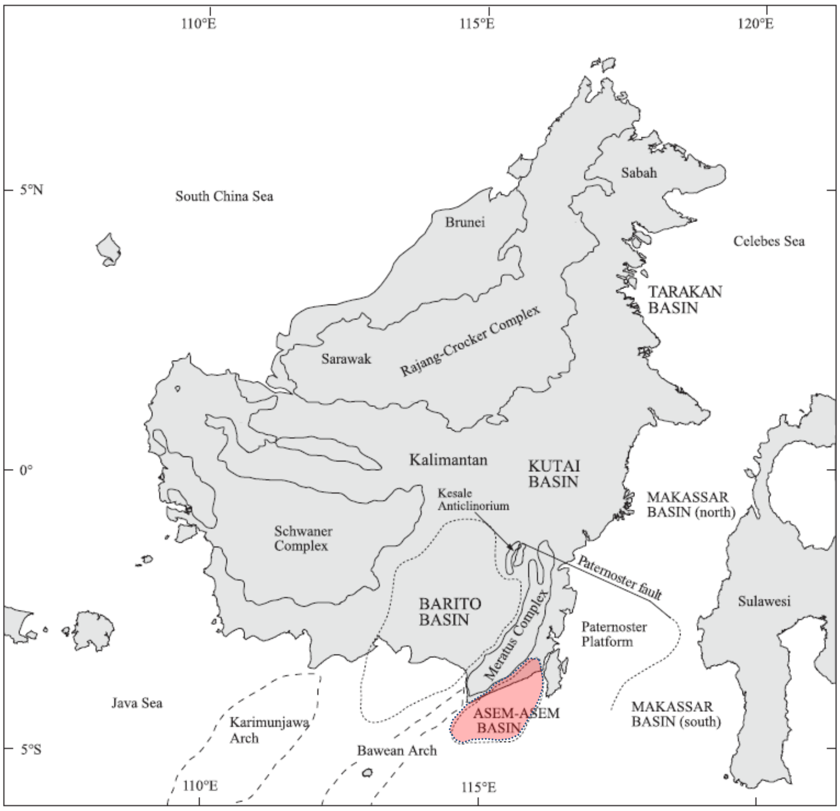

Figure 2 Location of Asam-Asam Basin in South Kalimantan (Base map: Witts et al (2012)

The basin contains a thick sequence of Cenozoic sediments interpreted broadly to record initiation of the basin, a marine transgression, a subsequent regression to terrestrial environments, and post-depositional folding and thrusting. The sequence comprises four formations – the Tanjung, Berai, Warukin and Dahor Formations – thought to be of Middle Eocene to Pleistocene age. However, since they are predominantly terrestrial deposits (above sea level), the precise stratigraphic ages of these rocks are difficult to determine and the basin's evolution remains poorly understood (Daulay, 2004). The coal seams belong to the late Miocene Warukin Formation and have a strike approximately SW-NE.

The Asam-Asam coal is generally known to have a high moisture content, low vitrinite reflectance, and contain high pyrite and high Fe2O3 in ash as the result of the high pyrite. Large resources of this coal exist near the surface. Therefore, AMD issues are quite common in this area.

The PT Jorong Barutama Greston coal mine

The PT Jorong Barutama Greston (PT JBG) located in South Kalimantan Province has operated since 1999. The mine produces low sulfur coal with a calorific value of 5300-5800 kcal/kg. There are 10 main coal seams with a thickness ranging from 1 to 34 m and some minor seams of 0.1 to 2 m thick. The coal bearing formation consists of claystone and sandstone intercalated with thin to medium siltstone. In general, the coal seams are classified into two zones, namely M-zone and U-zone. There are five coal seams in the M-zone; M1 (the oldest) to M5 (the youngest). Another five seams belong to the younger U-Zone (Gautama et al, 2014).

The main environmental issue is the overflow of acid water from the pit lakes. Although reclamation and re-vegetation in the surroundings of open pits is quite successful, there are still bare land areas which are believed to consist of potentially acid forming (PAF) material.

Soil and water

The range of pH values, measured in deionised water suspensions, for 63 soil samples collected by PT JBG was from 2.6 to 4.4 (median=3.5) and the following range of concentrations were measured for the samples:

Al: 1.55-18.63 meq/100g (median=4.19 meq/100g)

Fe: 29.38-1328.95 ppm (median= 195.34 ppm)

Mn: 1.17-152.52 ppm (median=8.76 ppm)

Pyrite: 0.03-0.64% (median = 0.15%)

There was a correlation between soil pH and exchangeable Al concentrations which indicates the general solubility of Al at low pH concentrations (Figure 3). The increase of Al concentrations with the percentage of pyrite in soil samples (Figure 4) may indicate the presence of Al sulfates in the soil samples. Iron did not show similar correlations with pH or pyrite which indicated the presence of other sources of Fe; for example, oxides.

Based on the limited soil chemistry data received from PT JBG, most parts of the soils under the revegetation program are extremely acidic with high concentrations of Al, Fe, and Mn. Although most of the planted vegetation (Paraserianthes falcataria) is relatively tolerant to these extreme soil chemistry conditions, the seepage runoff and leachates from these soils will be of poor quality. Therefore, soils need treatment with alkaline materials and/or organic wastes.

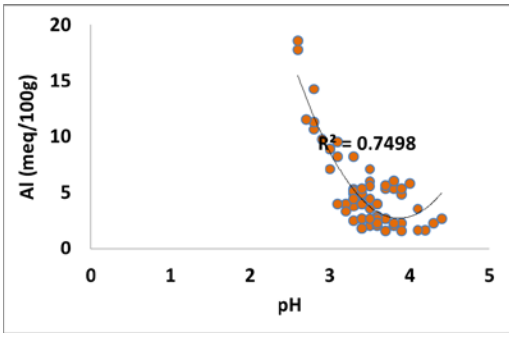

Figure 3 Change of aluminium concentrations with pH

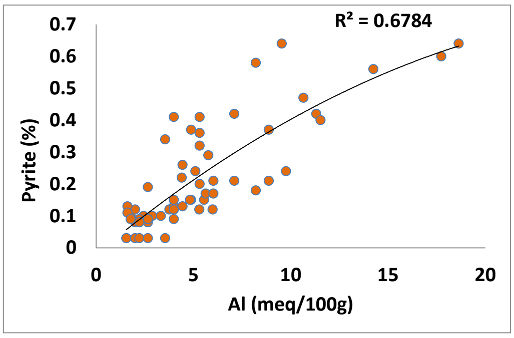

Figure 4 Correlation of aluminium and pyrite concentrations

Pit lakes

One major AMD issue is related to the shallow (up to 35 m deep) pit lakes in the area with volumes from approximately 1.7 to 8 million cubic meters. The pH of the lakes varies between 2.8 and 3.1. The pit lakes mainly fill with runoff water because of high annual rainfall (2600 mm/year) in the area (Figure 5). The pH of input water is around 6.0 and with interaction with surface geology it degrades and turns into acidic pit lake water, and overflows into local streams. The areas surrounding the pits have been rehabilitated and the company has been using lime dosing as a mitigation measure. Nevertheless, there are frequent episodes of AMD discharge and also the induced alkalinity is not homogeneously distributed at depth in the lake. With the current management practice, the pit lakes will continue to discharge AMD after mine closure which will be at odds with the regulations, i.e. SK. Governor South Kalimantan No. 28/1994.

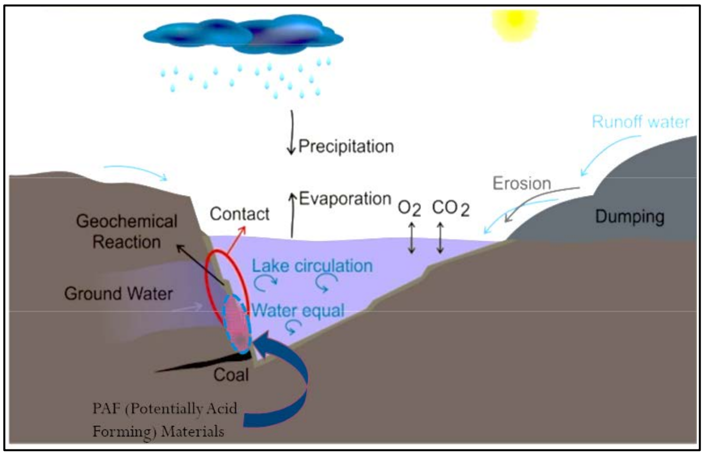

Figure 5 Schematic of pit lake and AMD formation process
(Source: Professor Rudy Sayoga Gautama)

Geochemical controls on Pit M4E water chemistry

The Pit M4E has formed since 2006 and contains approximately 8 million cubic meters of acidic water with a pH of 3. A lime mixing facility has been used to treat the lake water. A total of ~181 tons of lime was added into the lake from January to November 2013. Novianti (2014) calculated the amount of lime needed to neutralize the acidic water in M4E pit lake as 1050 tons/year. The groundwater contribution is relatively insignificant due to the large catchment area of the lake (~ 25ha).

Based on the available data (Table 1), the lowest measured pH is 2.88 and the highest is 3.15.

There is a positive correlation between pH and metal concentrations in the pit lake. The most obvious is the change in Fe, from 0.84 mg/L in the high pH range, to 17.5 mg/L in the lower pH range. Aluminium showed similar increases in concentration from 1.790 mg/L to 17.651 mg/L.

The primary acidity measured as proton (H+) concentrations, varied from 0.91 mg/L in the higher range of pH to 3.27 mg/L in the lower range. Most constituents (e.g. zinc and manganese) of the pit lake water exceed ANZECC (2000) guidelines for aquatic ecosystems.

Table 1 ME4 Pit water quality before liming. All concentration units are in mg/L. Data from Professor Rudy Sayoga Gautama.

Sample No.	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
T°C	27.3	26.3	26.4	26.4	26.5	26.4	26.3	26.3	26.4	26.5	26.4	26.5	26.7
Dissolved oxygen	6.7	6.81	6.58	6.61	6.59	6.56	6.53	6.49	6.58	6.61	6.68	6.56	6.53
pH	3.15	3.14	3.11	3.15	3.13	3.14	3.13	2.88	2.89	2.89	2.9	2.91	2.88
Hardness ($CaCO_3$)	118.51	126.41	126.41	128.39	126.41	130.36	136.29	120.49	92.83	90.86	96.78	96.78	99.75
Ca	13.05	21.12	21.21	18.76	17.13	18.76	17.13	6.53	8.16	6.53	5.71	8.16	8.16
Mg	20.88	17.86	17.86	19.82	20.33	20.3	22.73	25.32	17.61	18.12	20.06	18.57	19.29
Fe	0.842	0.842	0.842	0.735	0.416	0.95	0.95	14.66	14.23	14.65	14.65	17.15	14.23
K	5.86	2.35	2.28	0.32	7.03	5.98	0.41	0.54	0.66	3.94	0.25	2.8	1.05
Na	5.02	2.65	2.44	19.24	34.86	22.03	28.45	2.79	3.28	20.01	4.25	8.5	6.76
Cl	2.98	9.94	7.95	7.95	7.46	6.96	5.96	6.46	5.46	8.95	6.96	9.94	12.42
Al	1.79	1.877	2.089	1.902	1.941	2.104	1.773	16.686	16.261	16.268	17.651	21.283	17.299
Mn	3.78	6.02	5.12	4.23	5.12	4.67	6.48	24.76	3.78	5.57	3.78	4.23	4.67
Zn	0.435	0.464	0.445	0.416	0.502	0.518	0.543	0.627	0.613	0.689	0.706	0.738	0.761
Ba	0.156	0.262	0.121	0.113	0.157	0.141	0.153	0.034	0.038	0.038	0.035	0.048	0.046
Cr	<0.001	<0.001	0.001	<0.001	0.002	0.002	0.001	<0.001	<0.001	<0.001	<0.001	0.005	0.0005
F	0.403	1.42	1.68	1.61	1.56	1.45	1.6	1.18	1.51	1.44	1.63	1.96	1.73
SO_4	177	160.25	168.75	195	235.3	203.5	212.5	278	248	304	238	254.56	304
NH_3	0.062	0.345	0.374	0.11	0.169	0.121	0.292	0.085	0.062	0.126	0.102	0.108	0.11
NO_3	0.285	0.228	0.19	0.228	0.228	0.343	1.19	1.18	1.33	1.33	1.33	1.2	1.33
NO_2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CN	0.002	0.001	0.002	0.005	0.005	0.002	0.003	0.005	0.005	0.007	0.015	0.022	0.012
SiO_4	6.55	5.39	6.55	6.42	6.82	7.5	6.28	11.04	9.74	11.04	11.91	13.78	13.9
H^+	0.91	0.99	0.95	0.87	0.79	0.91	0.91	3.15	3.06	3.11	2.4	2.73	3.27
Acidity	58	60	60	62	58	62	58	273	244	238	234	257	244

The different types of processes with a direct or indirect influence on the water chemistry of pit lakes include: (1) physical processes such as advection, convection, diffusion, thermal and chemical stratification, evapoconcentration and dilution, and mixing with groundwater of different composition; 2) geochemical processes such as precipitation/dissolution and sorption/desorption, and; (3) biological processes such as bacterial oxidation/reduction and photosynthetic O2 production. Vertical mixing of the lake water column, called turnover, can significantly affect pit lake water chemistry. Pit lakes with a low relative depth typically undergo seasonal turnover (complete mixing of the entire water column) and are then termed holomictic (Wetzel, 2001).

Figure 5 shows a schematic of pit lakes processes at PT JBG. Currently, there is not enough data to investigate the physical, geochemical and biological processes within the pit lakes at PT JBG. Nevertheless, equilibrium modelling of the limited data can help to identify the concentrations of specific solutes as controlled by solid-phase solubilities, aqueous speciation, redox, and adsorption reactions.

The calculated saturation indexes (SI) in one representative sample (pH 3.15, sample number 25, Table 1) for most phases are highly negative, which indicates the high solubility of those phases. Barite, anhydrite, gibbsite, goethite, and gypsum have SIs closer to zero and may control the equilibrium chemistry of the pit lake (Figure 6). Equilibrium modelling with the other samples showed similar results.

The speciation modelling showed the abundance of Fe(III)-OH molecules which indicates potential precipitation of iron colloids (Figure 7). Generally, the most abundant colloids present in acid mine waters are Fe and Al oxides and clays (Nordstrom and Alpers, 1999). In this case, clays can be washed from mineral and rock fragment fines and transported to the M4E pit by water runoff, and/or be eroded from the pit walls. The colloids can play an important role in adsorption of trace metals. The speciation modelling also showed the presence of metals, for example zinc as free cations (Zn+2) which indicates higher level of bioavailability.

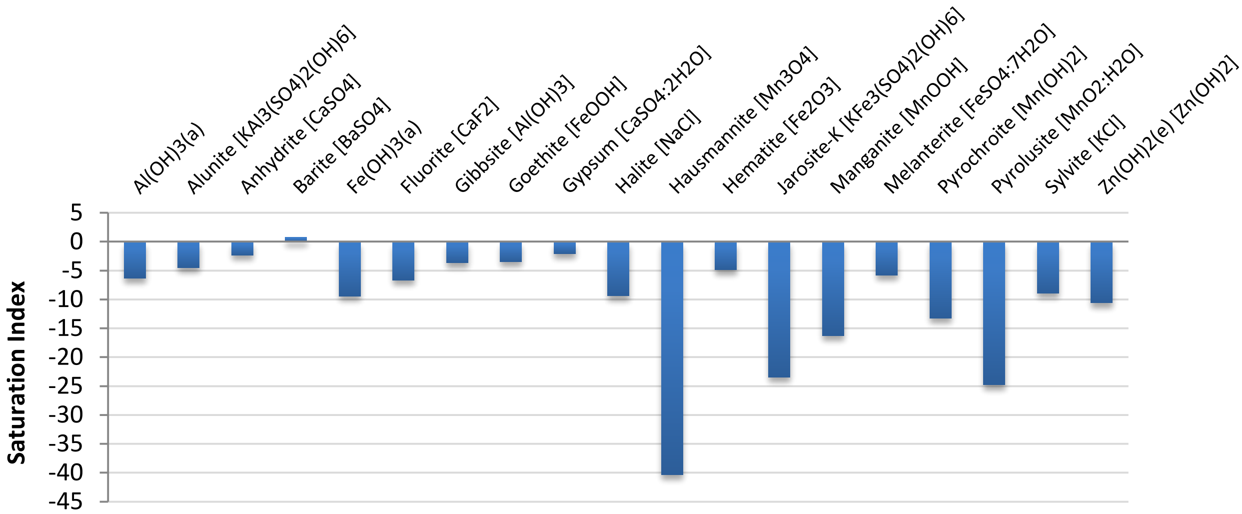

Figure 6 Saturation Indices of solid phases in pit lake water

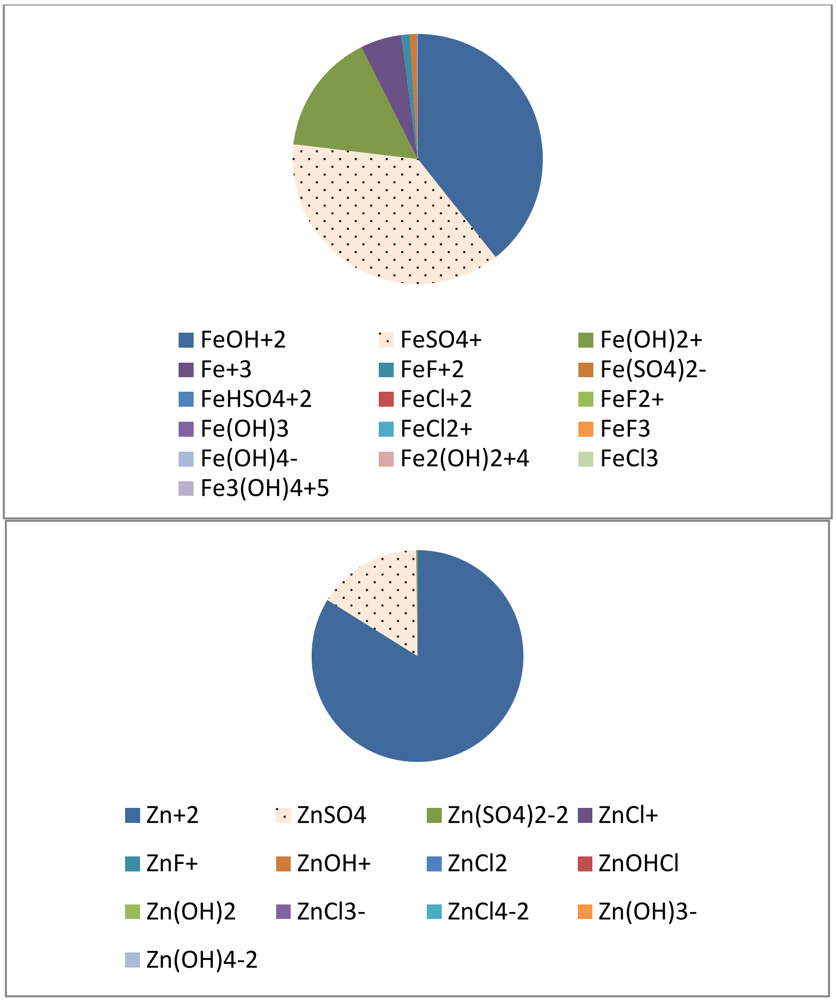

Figure 7 Percentages of dissolved chemical forms of ferric iron and zinc

AMD characterisation at PT JBG

There are uncertainties in the current geochemical protocols adapted by the company for the characterisation of rocks and AMD assessments and predictions. In the conventional approach to the calculation of Net Acid Production Potential (NAPP), usually Maximum Potential Acidity (MPA) is compared with the Acid Neutralising Capacity (ANC) of rocks. Often this comparison is based on total sulfur which can be misleading, if non-pyrite sources of sulfur are present in the sample.

In the new approach taken by the company (Figure 8) the Chromium Reducible Sulfur (CRS) (or sulfide sulfur) is measured on site and “Net Total Acid Production Potential (NTAPP)” is calculated by the difference between “Maximum Titratable Acidity (MTA)” (which is the sum of CRS and total actual acidity) and ANC.

This new set up, which was established in 2013 is a better way of assessing the AMD risk of each sample. However, it ignores an important source of acidity and metals which is metal acidity or secondary acidity as the result of the dissolution of secondary minerals. In other words the correlation between the mineralogy of spoils and the type and amount of acid produced and the type and amount of metals released is not clear. This is particularly important, as water quality results show for example with high manganese concentrations. A better understanding of the types of acidity, i.e. primary acidity as the result of sulfide oxidation and secondary acidity due to dissolution of minerals, is necessary for better management of AMD. Detail recommendations on AMD characterisation are provided later in the report.

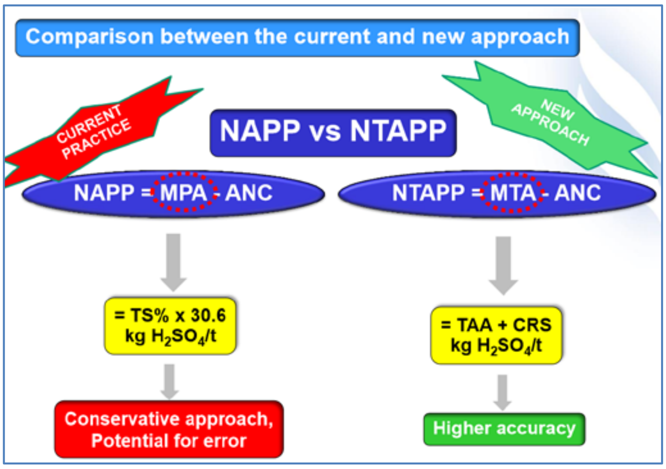

Figure 8 The AMD assessment approach at JBG mine

CONCLUSIONS

Periodic discharge of acidic water from the pit lakes is the major cause of acute acid and metalliferous drainage issues. Despite the rehabilitation of surrounding areas, the overland flow plays a significant role in transferring oxidation products into the pit lakes. Major processes that add to or remove chemicals from the lake may include runoff from the surrounding rehabilitated areas and the leaching of the pit walls, groundwater infow, precipitation, evaporation, biological processes, lake hydrodynamics, and geochemical equilibria.

The lakes show very high acidity, including proton acidity (free H+ ions), and mineral acidity, generated by the hydrolysis of hydrolizable cations such as Fe3+, Fe2+, Al3+, as pH increases. Currently, the site characterisation protocols do not include complete titration and measurement of mineral acidity either in the solid phase (rock, soil) or for the pit water. Iron is likely to be present in the form of chemical precipitates such as Fe(III) oxyhydroxides and oxyhydroxysulfates directly formed in the water column by oxidation and hydrolysis of dissolved Fe. Nanometric colloidal particles suspended in the water column can play an important role in the adsorption and transport of contaminants from the pit.

In the absence of timely hydrological and water quality data, particularly accurate water balance models, it is not sensible to propose a sustainable solution to mitigate AMD, neither at the source nor at discharge points. Lime dosing does not seem to be effective for a long period of time. A sustainable treatment option requires understanding potential stratification and overturing within the lakes, the role of sludge and secondary minerals, the hydrology of the lakes, and the geochemistry of surrounding areas. This also links to the closure plans for the mine site. The ideal option is a self-sustaining system in which the AMD process is prevented at source and/or mitigated through natural attenuation processes. Failing that, an option with minimum maintenance should be considered.

The illegal mining has contributed to the chronic AMD issues in the mine catchments. At-source control of AMD through mine planning and selective handling of overburden is almost impossible with opportunistic disturbance of the coal and waste piles by illegal miners.

RECOMMENDATIONS

Similar to pit lakes in other coal mining areas, for example those in Germany (Uhlman et al., 2004), possible remediation strategies for these lakes can be considered as flooding with alkalinity-buffered surface waters from surroundings; chemical treatment with alkaline substances such as limestone, lime, or sodium hydroxide; and the promotion of biological reductive processes. The objective of all of these strategies is the long-term decrease and elimination of acidity in the mine lakes, thereby increasing the pH to circumneutral values.

We recommend conducting a targeted investigative study into the hydrology, water balance, and geochemistry of the pit lakes, focusing on the largest lake (Pit M4E). The following is a broad outline of an indicative methodology for such a study.

1. Hydrological modelling of pit lake catchment

   An appropriate hydrological model will be developed for the local catchment. This requires to accurate characterisation of runoff from the pit lake catchment, rainfall, stream flow, evaporation, ground elevation data, pit water elevation data, aerial photography.

2. Modelling of pit lake water balance

   Using the hydrological model developed in Task 1, a water balance model should be developed for Pit M4E to serve the following purposes:

   - Prediction of time varying inflows and outflows from the pit lake to allow geochemical evaluation;
   - Prediction of pit lake levels post-closure (so, for example, dewatering rates can be adjusted to achieve specific water level targets).

   The water balance method relies on the estimation of inflow and outflow terms from the pit, with changes in pit level calculated from the change in storage of the pit lake. In a simple conceptual model the change in storage ΔS is given by:

   $$\Delta S = P + R + G - W - E$$

   where P is direct precipitation on the pit, R is runoff into the pit, G is groundwater inflow into the pit, W is groundwater withdrawal via pumping if applicable, and E is evaporation from the lake. Filling of the pit lakes is likely to be driven mainly by rainfall and runoff, as rainfall in South Kalimantan (typically in the order of 2.6 m/year) exceeds evaporation (typically around 1.5 m/year). The use of a water balance method, as opposed to a numerical groundwater flow model, is justified on the basis that detailed characterisation of the local hydrogeology and measured groundwater levels (required for numerical groundwater flow modelling) are likely to be unavailable or prohibitively expensive. The pit lake will be modelled as a simple well-mixed water body; this assumption is reasonable as Pit M4E is relatively shallow (up to 35 m deep), and because South Kalimantan experiences a tropical rain climate without a significant dry season. These factors mean that stratification of the pit lake is unlikely to be significant, and hence the well-mixed assumption is justified.

The most likely candidates for a simplified model are the widely used GoldSim software, or CWiMI's in-house modelling package, the HSM, developed specifically for simulation of mine water systems. Both these packages allow for long-term simulation of the dynamics of water storages, as well as stochastic/probabilistic analysis. Probabilistic analysis is particularly appropriate to this problem as it allows for the probability of AMD events to be quantified and the range of probable system responses for the pit lake to be elucidated. GoldSim also allows for models to be coupled to the common geochemical modelling software PHREEQC.

3. Geochemistry

In the absence of enough site-specific data to unravel geochemical processes, the identification of specific geochemical controls can provide useful guidance in the setup and application of geochemical models used to predict future water quality in the pit lakes. Further geochemical investigations should include:

- detailed characterisation of pit lake sediments, suspended particles, and wall-rock alterations;
- ultrafiltration to check the effect of colloidal matter. An important percentage of the concentration of most aqueous chemical constituents is not truly dissolved but present as colloidal matter. It is important to measure the particulate, colloidal, and dissolved fraction of contaminants in the lake;
- the titration of lake water with NaOH in the laboratory to measure the amount of alkalinity necessary to neutralize this acidity and raise the pH to the environmental guideline values. Modelling the titration curve of acidic water from the pit lake in detail in order to obtain a detailed understanding and a quantitative description of buffering mechanisms relevant to lake water neutralisation (e.g. Totsche et al. 2003);
- in-situ and periodic measurement of physico-chemical parameters inside and at the depth of water in the pit lake;

- the identification of the most relevant physicochemical processes by combining field and bench experiments with appropriate models, and collection of reliable to determine crucial model parameters that enable a long-term forecast of net acidity load from the lake.

From a social perspective a detailed study is required to:

- understand the company's efforts to engage with the 'illegal' or small scale miners that conduct activities within or nearby their mining leases; and to understand the nature of conflicts if any;
- diagnose the socio-economic conditions of the impacted village (Asam – Asam) and to understand the socio-economic characteristics of the 'illegal miners' and the main drivers for them to conduct such activities (e.g. to understand whether there is a link between poverty and illegal mining) and what options can be done to manage the illegal miners from the company perspective;
- promote dialogues between local authorities, local communities (including 'illegal' and small scale miners if they are from the nearby communities) and mining practitioners (large and medium/small scale) to understand the AMD risks to the external environment; to make them aware about the issues/risks; and to find ways to collectively manage the risks.

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Appendix 1: Geological map of Banjarmasin, Kalimantan (Geological Research and Development Centre, 1994)