Banpu Public Company Limited

Acid Mine Drainage Management

Management Standard

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Introduction

Acid Mine Drainage (AMD) is the formation and movement of highly acidic water rich in heavy metals. This acidic water forms through the chemical reaction of surface water (rainwater, snowmelt, pond water) and shallow subsurface water with rocks that contain sulfur-bearing minerals, resulting in sulfuric acid. The resulting fluids may be highly toxic and, when mixed with groundwater, surface water and soil, may have harmful effects on humans, animals and plants.

Banpu is aware of the AMD impact and therefore integrated AMD management into the environmental management system in order to ensure that the AMD impact of all operations are properly prevented, minimized and managed in accordance with the national/local regulations of all countries where the Company operates.

This standard practice manual of AMD management has been developed from Banpu Corporate HSEC Procedure: Acid Mine Drainage Management which focuses on the AMD management in part of both mineral waste and water.

Objective

The objective of this standard practice manual is:

• To provide information and guideline for the sites to establish their work procedure (WP) and/or work instruction (WI) (if applicable), and AMD management plan as well as implement AMD management program management program

Scope

This standard practice manual applies to all business functions in Banpu, its subsidiaries, and affiliates from corporate level down to country / business unit (BU) level and site level.

Definitions

Acid Mine Drainage (AMD):
Metal-laden solutions produced by the oxidative dissolution of iron sulfide minerals exposed to air, moisture, and acidophilic microbes during the mining of coal and metal deposits. AMD has traditionally been referred to as ‘acid mine drainage (AMD)’ or ‘acid rock drainage (ARD)’.

Potentially Acid Forming (PAF):
Geochemical classification criterion for a sample that has the potential to generate acid conditions.

Non-Acid Forming (NAF):
Geochemical classification criterion for a sample that will not generate acid conditions.

Process / Content

Acid Mine Drainage Management

Acid Mine Drainage (AMD) is the most common cause of mining activity. AMD occurs naturally within some environments as part of the rock weathering process and usually within rocks containing as abundance of sulfide minerals when exposed to water and oxygen (oxidizing condition). The oxidation of sulfide minerals consists of several reactions. Each sulfide mineral has a different oxidation rate. For example, marcasite and framboidal pyrite will oxidize quickly while crystalline pyrite will oxidize slowly (Acid Mine Drainage, USEPA). The partial list of sulfide mineral shown as follows,

Mineral	Composition
Pyrite	FeS_2
Marcasite	FeS_2
Chalcopyrite	$CuFeS_2$
Chalcocite	Cu_2S
Sphalerite	ZnS
Galena	PbS
Millerite	NiS
Pyrrhotite	$Fe_{1-x}S$ (where $0<x<0.2$)
Arsenopyrite	FeAsS
Cinnabar	HgS

Reference: Acid Mine Drainage, USEPA

Therefore, factors influence the quality of mine drainage including,
- Primary factors: the physical characteristics of mining waste that contained sulfide minerals.
- Secondary factors: the relative amount of water and oxygen in the environment which influences the amount and quality of acidic water.
- Tertiary factors: the neutralization of acid by the alkalinity released from the carbonate minerals in the mine waste and surrounding.

This can present a major risk to aquatic life, riparian vegetation and human uses of the water resource for many kilometers downstream from where it enters a waterway. Visual indicators of AMD can include:
- Red coloured or unnaturally clear water
- Orange–brown iron oxide precipitates in drainage lines (Figure 1)
- Dense coatings of green algae filaments on the bed of a stream with unnaturally clear water
- The death of fish or other aquatic organisms on mixing AMD with receiving water
- Precipitate formation on mixing AMD with groundwater inputs into stream channels or on mixing AMD with receiving surface waters, such as at stream junctions
- Poor productivity of revegetated areas (such as waste rock dump (WRD) covers)
- Vegetation dieback or soil scalds (such as bare areas)
- Deposits of white or coloured salts forming along the banks of stream channels and along the toes of WRDs during the dry season

Figure 1: Orange Coatings on Rocks and Precipitates Forming in a Drainage Line Downstream of an AMD Source (Australian Government, 2016)

The crucial step in leading practice management of AMD is to assess the risk as early as possible. ‘Risk’ includes environmental, human health, commercial, reputation, legal and regulatory risks. The progressive evaluation of AMD risk, begun during exploration and continuing through the feasibility evaluation stage, provides the data necessary to quantify potential impacts and management costs before significant disturbance of sulfidic material. When projects proceed at sites where AMD is a potential risk, efforts should focus on prevention or minimization, rather than on control or treatment.

The overall goal of AMD management strategies should be to minimize or, wherever possible, eliminate the exposure to air and/or water of reactive sulfidic material, now and into the future. This can only be achieved if site planners and managers have a thorough understanding of the AMD risks of the materials disturbed (or exposed to air) as a result of mining, and integrate appropriate management and mitigation strategies into the mine plan. Apart from the strategies, an AMD management plan for site operations and closure should be developed during the feasibility phase as well as be implemented and updated during the operations phase in response to increased knowledge and/or change in the project scope.

Monitoring data should be used to periodically assess the ongoing performance of the initially implemented AMD management strategy, and changes should be made if the required performance is not being achieved. The effectiveness of strategies being used for operational management and proposed to be used for the post-closure minimization of AMD risk should be tested by numerical modelling and validated by in situ monitoring and results from field trials well in advance of closure to confirm their effective performance.

Strategies for managing AMD fall into three general categories:
- Minimizing oxidation and the transport of oxidation products
- Controls to reduce contaminant loads escaping to the environment
- Active or passive treatment to allow water re-use or discharge

The identification of optimal minimization and control strategies for a particular site will depend on climate, topography, the mining method, the material type (such as waste rock, tailings, wall rock and heap leach material), soil and rock types, mineralogy and available neutralization resources, and inter- relationships between those factors. The selective placement and encapsulation of waste materials based on their known physical and AMD-generating characteristics and risk profile is often the preferred AMD management practice during mine operations.

AMD Control Measures for Mineral Waste

Management of Waste Rock Dumps to Minimize AMD

For surface waste rock dumps (WRDs), including those in valley-fill structures, potentially acid-forming (PAF) or high solute load potential waste rock should be identified and managed appropriately from the start of operations. This category of waste should be selectively placed and encapsulated with AMD- benign material (low AMD risk or non-acid forming (NAF) waste and/or waste rock with excess acid- neutralizing capacity (ANC)) (see Figure 2). The AMD risk presented by a waste type, and how it is managed, should be based on its solute load potential, rather than on predicted pH alone.

The entry of run-off or near-surface groundwater into the base of a WRD is a potential hazard that should be controlled. The most effective management strategy to limit the entry of surface flows into a WRD is to intercept clean rainfall run-off by diversion drains located upgradient of the WRD.

Depending on the topography of the WRD, a pad of NAF waste rock may also need to be placed first to provide a non-contaminating flow path for rainfall run-off from upstream of the pile. Otherwise, the run- off may find its way along buried drainage channels and streams beneath the pile. There may also be a need to provide a sealing layer over buried drainage lines to limit the potential migration of contaminated seepage from the PAF waste rock placed above them. Alternatively, free-draining NAF waste rock could be taken to full height above natural drainage lines, although this would require a large supply of non-contaminating waste rock.

Wherever possible, high AMD risk sulfidic waste rock should not be deposited so that it lies beneath the outer slopes of a WRD, as slopes are difficult to seal and more readily allow oxygen ingress and rainfall infiltration. A wide-side encapsulation (Figure 2) by NAF waste rock is required so that any rainfall infiltration into the operational and final side slopes will not intersect PAF or high solute load potential waste rock. The tops of waste dumps undergoing construction, and with centrally located high AMD risk material, should be progressively covered between lifts by a compacted layer of NAF waste rock. This should ideally be done before each wet season to limit the infiltration of rainfall into the PAF waste rock during operations and to reduce the time available for oxidation. At closure, a low net percolation or rainfall-shedding, non-contaminating cover is required on the final flat top of the WRD and on any residual benches.

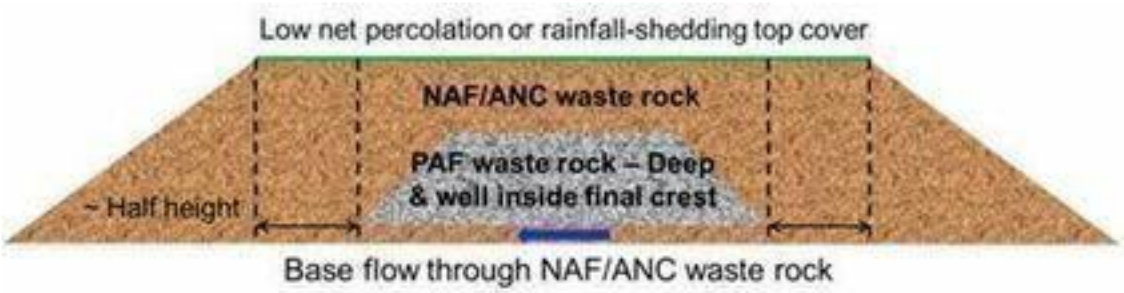

Figure 2: Encapsulation of Coarse-grained Reactive Waste (Australian Government, 2016)

To be able to effectively manage waste rock, it is essential to continuously record the volumes of the different waste rock types and their locations in the evolving WRD and to regularly review waste rock placement to ensure that the waste rock management plan is being appropriately implemented. This information should also be used to produce an evolving 3D block model of the WRD, which will greatly facilitate closure planning by providing a robust basis for testing the efficacy of proposed designs to limit AMD risk. This testing can be undertaken using computer models.

Management of Tailings to Minimize AMD

In some mining operations, there may be byproducts called tailings. Because tailings are conventionally deposited in slurry form (at various solids concentrations), the surface storage requires some containment or encapsulation (Figure 3). However, the form of encapsulation varies. A base liner may or may not be required, depending on the ground conditions and the risk posed by the tailings water.

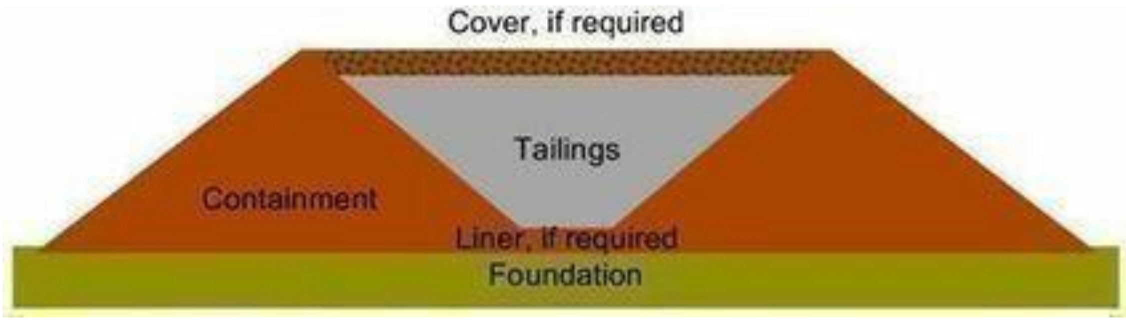

Figure 3: Encapsulation of Reactive Tailings (Australian Government, 2016)

In the early phases of a mine's life, the containment wall generally comprises borrow material or run-of mine weathered rock. Later, it may involve the use of rehandled dry tailings, with an outer protection of benign waste rock and/or soil. In some cases, where excess NAF waste rock is available and the tailings storage facility (TSF) is in close proximity to the pit, the perimeter of the TSF may be encapsulated by a thick layer of this rock. This has the added advantage of providing a buffer against the possible future loss of encapsulation through erosion.

The tailings should be deposited at as high a percentage of solids as possible to limit the amount of pore water available to report as seepage. This is facilitated by the use of high-rate thickeners or paste tailings technology. Evaporative drying by cycling tailings deposition between cells, potentially combined with dry stacking, should be taken advantage of where possible to limit seepage during operations. However, this strategy may also expose sulfidic tailings to oxidation.

The impact of ongoing rainfall run-off following the closure of a TSF needs to be considered. For example, this may require the installation of a low net percolation surface cover to minimize infiltration and a spillway for the release of water to relieve the head of water that would otherwise drive vertical seepage of contaminated pore water or cause the catastrophic collapse of the containment walls.

Several strategies are available for reducing the future potential for tailings to generate AMD, depending on whether the tailings have been deposited in an above-ground constructed TSF or below ground in a mined-out pit. Leading practice in this area continues to evolve. There are no quick fixes or one-size-fits-all solutions to AMD problems, and specialist expertise is often needed to develop the most appropriate management strategy.

AMD Control Measures for Water

Whereas AMD from mines waste could be controlled by encapsulation, there will be runoff from pit walls or other areas within mining area. This AMD will need to be managed and controlled using the appropriate water management strategies and potential water treatment. The AMD treatment measures could include:

1. Passive treatment: Passive treatment frameworks for AMD are expected to redesign and also enhance the nature of water that goes across them. Passive treatment system depends on naturally occurring biochemical, geochemical, and physical processes e.g., aerobic wetland, compost / anaerobic wetlands, Open limestone drainage (ALD), diversion wells, successive alkalinity-producing systems (SAPS), vertical flow reactors (VFR), pyrolusite process.

2. Active treatment: Active treatment is also known as chemical treatment includes addition of chemicals to the water to increase pH and accelerate metals e.g., dosing with alkali, reverse osmosis, sedimentation, sulfidization, ion exchange. Commonly utilized chemicals i.e., limestone, hydrated lime, stone quicklime, caustic soda, ammonia, and steel slag.

Reference

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● U.S. Environmental Protection Agency (USEPA), Acid Mine Drainage Prediction, 1994