Base Metal and Iron Ore Mining

Industry Description and Practices

This document addresses the mining of ores of base metals (copper, lead, nickel, and zinc) and of iron. The documents on Aluminum and on Coal Mining and Production also deal with mining activities.

The major phases in mine development are (a) exploration; (b) mine development; c) extraction (underground and open pit) and mine operation; (d) ore beneficiation; (e) storage and transport of ore; and (f) mine closure and reclamation. This document focuses on the development, operation, and closure phases.

Waste Characteristics

The volume of solid waste generated, including tailings from processing, is one of the main pollution concerns in the mining industry. Removal of overburden to access the ore can pose major problems in storage and reclamation. The overburden (waste-to-ore) ratio for surface mining of metal ores generally ranges from 2:1 to 8:1, depending on local conditions. The ratio for solid wastes from underground mining is typically 0.2:1. Where concentration or other processing of the ore is done on site, the tailings generated also have to be managed. Ores with a low metal content, say, less than 0.4%, generate significant quantities of tailings.

In certain mines where ores have high sulfur content, drainage from mine workings and waste heaps can become highly acidic and can contain high concentrations of dissolved heavy metals. This acid mine drainage (AMD) can have a pH of 3 or lower; sulfate levels of 800–1,800 milligrams per liter (mg/l); copper levels up to 50 mg/l; iron levels up to 1,000 mg/l; lead levels up to 12 mg/l; zinc levels up to 1,700 mg/l; and cadmium levels of several milligrams per liter, depending on the contents of the ore. Effluent from tailings ponds may contain concentrations of chromium of several milligrams per liter. Base metal mining tailings decant may contain high concentrations of thiosalts. Chemicals used in flotation and other metal concentration processes could create toxicity problems when released in effluents.

Surface runoffs may also pose significant environmental problems through erosion and carryover of tailings and other mining residues. Explosives such as ammonium nitrate may be present in surface runoff. Transport of mined material and machinery maintenance and repair can lead to contamination of surface water.

Significant levels of dust, above 3 kilograms per ton (kg/t) of ore mined, and ranging from 0.003 to 27 kg/t, may be generated by extraction activities, crushing, ore beneficiation, transport and traffic, and wind-borne losses. Significant releases of dust containing metals, including mercury, may result from the drying of the ore concentrate. Fires may result from the oxidation of sulfide-bearing materials and can present a significant hazard.

Pollution Prevention and Control

The critical factors in good environmental performance in mining are adequate planning and effective management and implementation. Responsibilities for the implementation and monitoring of environmental measures should be specifically assigned. Before mining begins, a mining plan and a mine closure and reclamation plan must be prepared and approved. These plans should be updated regularly as mining progresses.

Development Plans

Development plans define the sequence and nature of extraction operations and detail the methods to be used in closure and restoration. At a minimum, the plans must address the following:

- Removal, proper storage, and management of topsoil
- Early restoration of worked-out areas and of spoil heaps to minimize the extent of open areas
- Identification of potential areas for AMD generation, followed by planning for successive remediation of pyrites to reduce AMD generation
- A water management plan focusing on the effective use of mine water for operations (with recirculation of process water) and for postclosure
- Extraction methods in relation to subsidence and to surface use
- Development of restoration and vegetation methods that are appropriate to the specific site conditions
- Blasting methods that minimize noise and vibrations.

The development plan normally contains specific sections dealing with erosion and sediment control, tailings disposal, mine closure and site restoration, and operating measures. These are discussed next.

Erosion and Sediment Control

An erosion and sediment control plan should be prepared. It should include measures or methods, appropriate to the situation, for intercepting, diverting, or otherwise reducing stormwater runoff from exposed soil surfaces, tailings dams, and waste rock dumps. Both vegetative and nonvegetative soil stabilization measures should be an integral part of the erosion control plan. Sediment control structures (for example, detention and retention basins) should be provided to intercept and treat surface runoff prior to discharge. All erosion control and sediment containment facilities must receive proper maintenance during the life of the project.

Tailings Disposal

Tailings must be managed to optimize human safety and environmental protection. On-land tailings impoundment systems must be designed and constructed in accordance with internationally recognized engineering practices, local seismic conditions, and precipitation conditions (to accommodate surface run-on). The designs should address the structural integrity of the tailings dams or deposits even post-closure. On-land disposal systems should be designed to isolate acid leachate-generating material from oxidation and percolating water. Marine and riverine discharges are normally not acceptable and should be considered only when on-land disposal would pose an environmental risk and it can be demonstrated that such discharges will not have a significant adverse effect on downstream coastal or riverine resources. Riverine discharges are acceptable only when justified on the basis of an environmental analysis of the alternatives and the effects on aquatic resources and downstream users of riverine resources.

The design of the tailings management system must address postclosure issues such as the long-term geotechnical stability of the impoundment, the chemical stability of the tailings, long-term surface and groundwater management (including provisions for long-term spillway capacity requirements), and restoration.

Mine Closure and Restoration Plan

The closure and restoration plan should cover reclamation of tailings deposits, waste rock deposits, any open pit areas, sedimentation basins, and abandoned mine, mill, and camp sites. Mine reclamation plans should incorporate the following:

- Return of the land to conditions capable of supporting prior land use, equivalent uses, or other acceptable uses
- Elimination of significant adverse effects on adjacent water resources
- Use of waste rock for backfill and of topsoil (or other acceptable materials) for reclamation to the extent feasible

- Contouring of slopes to minimize erosion and runoff
- Planting of native species of vegetation and of other species that are environmentally acceptable, to prevent erosion and to encourage self-sustaining development of a productive ecosystem on the reclaimed land
- Postclosure management of AMD and tailings; reduction of AMD formation by sealing off pyrite-containing waste from oxidation and percolating water
- Budget and schedule for pre- and postclosure reclamation activities.
- Sealing or securing of all shaft openings and mine adits on closure of the mine.

Money should be reserved over the life of the mine to cover the costs associated with mine closure. The amount of money and the type of financing required will depend on a number of factors such as the projected life of the mine, the nature of the operations, the complexity of environmental issues, the financial and environmental management capacity of the borrower or project sponsor, and the jurisdiction in which the mine is located. The mine reclamation and closure plan, the timing of its submission, and financing of activities under the plan should be discussed and agreed on with the borrower or sponsor as early as possible.

Operating Measures

Other recommended pollution prevention measures include:

- Progressive backfilling to minimize land disturbances
- Use of dust control equipment on dryers and of pressure-air dryers instead of fuel-based drum dryers to dry concentrations.
- Use of covers or control devices for crushing and milling to avoid the generation of dust
- Minimization of AMD generation by reducing disturbed areas and isolating drainage systems
- Diversion of leachates from waste heaps to avoid contact with and contamination of surface water and groundwater
- Minimization of freshwater intake; recycling of tailings decant water and wastewater from the concentration process to minimize contaminated discharges to the extent feasible
- Collection of leachates from tailings ponds and treatment before discharge, with sufficient residence time in the tailings pond to ensure thiosalt oxidation; provision of buffer capacity for the rainy season
- Use of ditches to divert surface runoff from tailing ponds
- Use of dust suppression measures (wetting work areas, roads, and storage piles; installing equipment covers; minimizing drop distances by using adjustable height conveyors; and using dust hoods and shields)
- Collection and recycling of waste oils and lubricants
- Prevention of spills of chemicals (including ammonium nitrate, if used in blasting operations)
- Provision of appropriate storage areas for chemicals and fuels
- Avoidance of the use of toxic floatation agents
- Control of noise through the use of berms and mufflers; control of noise and vibrations by means of sequenced blasting.

Treatment Technologies

Filters for crushers, grinding mills, and dryers are used to control dust emissions.

AMD and wastewaters are typically dealt with by using physical-chemical treatment techniques such as neutralization, precipitation, flocculation, coagulation, settling, and filtration. In some cases, cyanide oxidation and ion exchange may also have to be performed. Chrome reduction may be needed for floatation water.

Emissions Guidelines

Emissions levels for the design and operation of each project must be established through the environmental assessment (EA) process on the basis of country legislation and the *Pollution Prevention and Abatement Handbook,* as applied to local conditions. The emissions levels selected must be justified in the EA and acceptable to the World Bank Group.

The guidelines given below present emissions levels normally acceptable to the World Bank Group in making decisions regarding provision of World Bank Group assistance. Any deviations from these levels must be described in the World Bank Group project documentation. The emissions levels given here can be consistently achieved by well-designed, well-operated, and well-maintained pollution control systems.

The guidelines are expressed as concentrations, to facilitate monitoring. Dilution of air emissions or effluents to achieve these guidelines is unacceptable.

All of the maximum levels should be achieved for at least 95% of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours.

Liquid Effluents

Table 1 gives the effluent levels to be achieved during operation and after mine closure.

Ambient Noise

Noise abatement measures should achieve either the levels given below or a maximum increase in background levels of 3 decibels (measured on the A scale) [dB(A)]. Measurements are to be taken at noise receptors located outside the project property boundary.

Table 1. Effluents from Base Metal and Iron Ore Mining

(milligrams per liter, except for pH)

Parameter	*Maximum value*
pH	6–9
TSS	50
Oil and grease	10
Cyanide	1.0
Free	0.1
Weak acid dissociable (WAD)	0.5
COD	150
Arsenic	0.1
Cadmium	0.1
Chromium (hexavalent)	0.1
Copper	0.5
Iron	3.5
Lead	0.2
Mercury	0.01
Nickel	0.5
Zinc	2
Total metals	10

	Maximum allowable log equivalent (hourly measurements), in dB(A)	
Receptor	*Day (07:00–22:00)*	*Night (22:00–07:00)*
Residential, institutional, educational	55	45
Industrial, commercial	70	70

Monitoring and Reporting

Liquid effluents, including tailings dam outflows, should be monitored daily for pH and suspended solids. Metals and, when appropriate, thiosalts and floatation chemicals should be monitored on a monthly basis. If treatment is required to control soluble metals, metals and other parameters such as turbidity should be monitored more frequently. Frequent sampling may be required during start-up and upset conditions.

Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Records of monitoring results should be kept in an acceptable format. The results should be reported to the responsible authorities and relevant parties, as required.

Key Issues

The key production and control practices that will lead to compliance with emissions requirements can be summarized as follows:

Develop a comprehensive environmental and mine management plan to include:

- Restoration and rehabilitation of disturbed areas
- Identification and management of AMD sources
- Water management for operations and postclosure conditions
- Management and sealing of tailings

Develop and implement a post-closure plan to include:

- Restoration of disturbed areas
- Long-term geotechnical and chemical stability of tailings
- Adequate spillway capacity for the tailings pond overflow
- Management of AMD, water drainage, and surface runoff

Sources

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