ACID WASTE ROCK MANAGEMENT AT CANADIAN BASE METAL MINES[1]

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Abstract.--An inventory of acid waste rock management methods at Canadian base metal mines was undertaken with a view to defining the current state of the art and areas of future research. The status of alternative methods such as insitu neutralization, underwater disposal, sealing techniques, bactericides, segregation, and treatment are reviewed. It is concluded that preventative management methods are in their infancy and several areas of research are recommended with emphasis on cellular design of waste dumps, various types of cover, and underwater disposal.

INTRODUCTION

In 1983, the Canadian base metal mining industry and Federal government initiated a joint program of applied research directed at determining solutions to the long-term management of reactive acid tailings. The program is referred to as the Reactive Acid Tailings (RATS) program and is scheduled for completion in 1992.

During the fall of 1986, it was decided to broaden the scope of the RATS Program to include acid waste rock (AWR). A study was therefore initiated to prepare an inventory of acid waste rock at Canadian base metal mines, to define existing and potential acid waste rock management methods, and to define research and development requirements that might be integrated into the RATS program. This paper is based on the findings of the Acid Waste Rock Study (Nolan, Davis & Associates Ltd., 1987).

DESCRIPTION OF STUDY

Nature of Acid Waste Rock

Base metal mining operations in Canada employ both open-pit and underground mining methods. In sulphidic areas, both can result in acid-generating waste rock. For underground mines, the volume represents primarily development rock and is therefore significantly less than that for most open-pit operations where the ratio of waste to mill feed is typically in the order of 2 to 2.5. The generation of waste rock at open-pit mines is a continuing function of the mining operation, meaning that waste disposal areas must remain active throughout the life of the mine. The characteristics of base metal mine waste rock are highly site specific, but it tends to be less friable than most coal wastes, thus resulting in waste dumps that are very permeable to air and water unless preventative measures are applied.

Occurrence of Acid Waste Rock in Canada

The approximate distribution of acid waste rock at base metal mines in Canada is shown in table 1. It is important to appreciate that the tonnage figures given are approximate and that they represent only base metal properties. Acid waste rock is also associated with a number of other minerals in Canada including gold, uranium, and coal which were not included in the study.

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Table 1.--Distribution of AWR at Canadian base metal mines.

Province/Territory	Number of Properties with AWR	Approx. Tonnes
British Columbia	9	250,000,000
Alberta	0	---
Saskatchewan	0	---
Manitoba	9	100,000
Ontario	16	50,000,000
Quebec	9	250,000
New Brunswick	6	4,000,000
Nova Scotia	0	---
Prince Edward Island	0	---
Newfoundland & Labrador	4	100,000
Yukon	2	10,000,000
Northwest Territories	1	500,000
	TOTAL: 56	315,000,000

Acid waste rock management is regarded as an important environmental issue in British Columbia and New Brunswick. In other regions containing reactive mine wastes, the management of acid-generating tailings is regarded as a more important priority within the base metal mining sector.

The technology to collect and treat contaminated leachate from AWR piles is well established and offsite contamination was found to be a problem only at abandoned properties where these practices are not maintained (10 of the 56 properties identified).

The inventory also showed that the application of preventative management methods for AWR is in its infancy in Canada, as elsewhere, and that there is in fact no proven method of AWR management for which back-up leachate collection and treatment is not required in most circumstances, with the possible exception of underwater disposal.

Acid Generation in Waste Piles

Factors influencing acid generation in pyritic waste dumps include pH (fig. 1); the amount of oxygen at the pyrite surface; the morphology of the sulphide minerals present; temperature (Morth 1965); the rate at which reaction products are transported away from the reaction site (Knapp 1987); the buffering capacity of the waste rock at the reaction site; humidity; and the availability of carbon dioxide, nutrients, and trace elements essential to microorganism growth.

John (1987) reports the most critical factor in the oxidation of pyrite to be the availability of oxygen and that the oxygen concentration required for the support of bacterially mediated oxidation is 0.5 mg/L (1.6 mol fraction percent). Nicholson (1984) shows that the relationship between oxidation rate and oxygen concentration is nonlinear and attributes this to complex adsorption-desorption mechanisms at the reaction site.

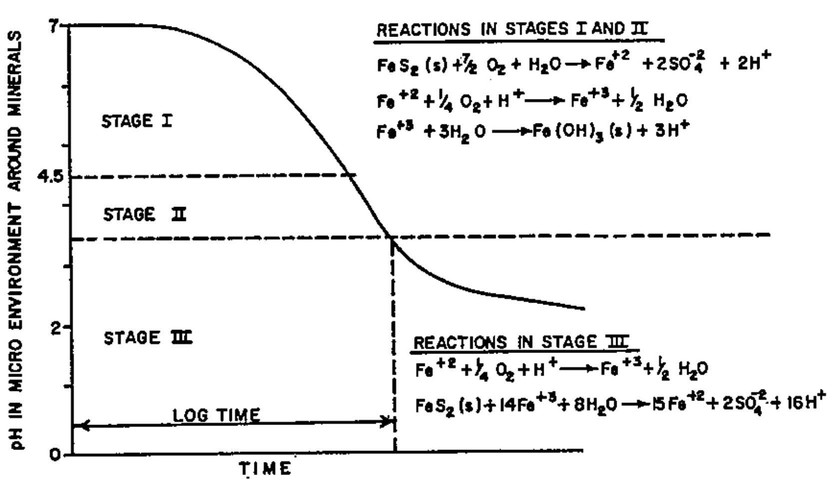

FIGURE I - STAGES IN THE FORMATION OF ACID MINE DRAINAGE
AFTER FERGUSON & ERICKSON, 1987

An insight into the factors influencing the generation of pollutants in waste rock dumps can be obtained by reviewing the literature on heap leaching for beneficiation purposes. The efficiency with which air is drawn into a heap leach pile is recognized as a key parameter (Cathles and Apps 1975). Good leachate qualities for beneficiation are dependent on maintaining air as the main source of oxidation rather than dissolved oxygen in the leach solution; this is a factor which should be kept in mind when trying to minimize waste dump contaminate leaching. Cathles and Schlitt (1980) conclude from the development of a two-dimensional dump leach model that beneficiation leaching of copper from low-grade dumps is fastest for dumps of 15 - 30 m height, that permeability of the dump is very important, and that leaching is facilitated if the leach solutions are preferentially supplied to the hot, near-edge portions of the dump.

Thus, one would conclude from these findings that to minimize leachate production in acid waste rock piles, one should reduce the permeability of the dump to air, try to prevent the exothermic oxidation reaction from significantly raising the dump temperature, minimize leachate transport, and prevent the ingress of seepage to the outer portions of the dump.

U.S. Experience with Acid Coal Spoils

Most of the literature specifically addressing the issue of acid waste rock management has developed as a result of surface coal mine operations in the Eastern United States. Although the basic objectives are the same, the practical considerations in relation to materials handling are quite different at a strip mining operation from those of a hard-rock open-pit situation common to base metal mining.

Several waste management principles that are applicable to hard-rock operations are identified in the literature pertaining to coal wastes. Cathles (1982), for example, compares the management of coal spoil piles to beneficiation leaching and emphasizes the importance of reclaiming pyritic spoils as soon as possible after mining in order to limit the oxidation of the spoil to the limited potential of "buried air". He recommends the following three steps to reduce the amount of acid generated:

1. Bury and cover the spoil as soon as possible after mining.

2. Compact spoil piles to eliminate air convection and reduce oxygen diffusion into the pile.

3. Consider the addition of bactericides to the pile.

Cathles, in the same reference, also states that while the burial of coal waste below the water table is not always possible, "a few feet of water will reduce the pyrite oxidation rate effectively to zero".

Erickson (1987) confirms that the current practice for the disposal of coal spoils in the United States now involves placement in optimized sites with compaction of the material during placement, followed by covering and revegetation.

Infanger and Hood (1980) report that the sequence in which overburden materials are placed in relation to acid coal spoils has a marked effect on leachate quality. In general, the more alkaline materials should be placed above the acid-producing material, and if possible, the pyrite layer should also be placed below the water table.

Many coal mine spoils in the Appalachian region of the United States produce low amounts of acidity (less than 30 mg $CaCO_3$/L per 100 g sample). In such cases, it has been demonstrated that mixing in the equivalent of a 0.3-m layer of limestone will inhibit acid production in the top 3 m of spoil, thus effectively arresting the leachate problem (Williams et al. 1982). Other researchers on acid coal spoils indicate that the placement of soil covers in excess of 0.6 m provides a preferable treatment technique to the use of ameliorants such as lime, limestone, or sewage sludge (Apel 1982).

Revegetation can provide an aesthetically pleasing cover to reclaimed spoil areas and will stabilize the surface from erosion. However, it is recognized by a number of authors (e.g., Farmer and Richardson 1981) that revegetation in itself will not curtail acid generation in spoil piles. This finding is supported by Veldhuizen et al. (1987) in relation to revegetation trials on acid-generating base metal tailings. They conclude "direct vegetation of reactive tailings does not restrict pyrite oxidation nor does it limit water infiltration to significantly reduce water flow from the impoundment".

Carruccio and Geidel (1987) report the use of alkaline trenches as a successful approach to shifting high acid leachate spoil systems towards more alkaline regimes.

Hard Waste Rock Management

There is very little literature on the management of reactive hard rock wastes typical of base metal mines in Canada. Eger and Lapakko (1981) report a series of leaching tests undertaken on experimental stockpiles containing metal sulphide wastes at the Minnamar site in northeastern Minnesota. They concluded that covers consisting of 18 cm of topsoil and 30 cm of sandy till over 28 cm of coarse sand were more effective in reducing the quality and quantity of leachate than a cover consisting only of 29 cm of coarse sand.

Work undertaken on the covering of two pyritic waste rock dumps at the Rum Jungle Mine in the Northern Territory of Australia has been reported by several authors. Harries and Ritchie (1986) describe the reclamation measures applied to the two dumps which contain approximately 4×10^6 tonnes and 0.8×10^6 tonnes of material. Essentially, the sides of the dumps were worked to give a maximum slope of 1 vertical to 3 horizontal with a berm half way down the slope. Engineered drop structures were provided to take surface water from the berm to the base of the dump. The dump was then covered with 3 layers of material:

-on the top:

225 mm compacted clay followed by 253 mm

of clayey sand and a minimum of 150 mm of gravelly clayey sand

-on the sides:

300 mm compacted clay followed by 300 mm clayey sand and 150 mm broken rock

Vegetation was established on the surface to provide protection and improve the aesthetics of the dump.

The trial showed that the cover effectively stopped air transport through the dump both by diffusion and thermal convection, thereby lowering oxidation rates within the dump. However, the authors report that air is subsequently penetrating the cover in some areas, possibly due to root penetration, and advise that it is not yet clear whether the oxidation rate will remain at a low level over the course of time.

Bell (1987) advocates the use of a cellular form of construction for acid waste rock piles in situations where there is a sufficient volume of impermeable material within a reasonable haulage distance but emphasizes that this approach has yet to be evaluated under pilot or operating conditions. Patterson (1987) reports the use of till to provide a horizontal seal and sideslope cover to the waste rock dump at the Equity Silver Mine in British Columbia. He states that this treatment represents a small incremental cost over normal operating expenditures and has resulted in a slight downward trend in leachate acidity and metal levels.

Application of sodium lauryl sulphate to the Equity Silver dump was tested after laboratory simulations produced promising results. However, the rock surface could not be effectively saturated and the surfactant biodegraded rapidly under the acidic conditions present.

Taylor (1984) describes the acid waste management systems at the Gibraltar Mine in British Columbia, and states that the possibility of sealing the large waste dumps was considered and rejected as logistically unfeasible. The decision was therefore made to treat contaminated leachate from the dumps rather than apply preventative measures.

This brief review clearly defines the lack of proven technology for the effective long-term management of acid waste rock dumps in Canada or elsewhere. There is, however, a general recognition that preventative methods must reduce the availability of oxygen within the dump to levels of less than 0.5 mg/L; that the ingress of water must be reduced to an absolute minimum to restrict the flushing of reaction products, that the voids ratio should be minimized by compaction of the waste so as to reduce the volumes of entrapped and induced air, and that siting of the dump with respect to surface and groundwater hydrology is of paramount importance.

Review of Alternative AWR Mangement Strategies

The potential options available for AWR management and their economic impact on the profitability of an operation are highly mine-specific. At the present time, collection and treatment of contaminated leachates in perpetuity is the only generally available long-term management option. It is in this perspective that the following alternative management strategies are reviewed:

In Situ Neutralization

In situ neutralization can involve either the addition of alkaline materials such as limestone to the waste rock or alternatively, the blending of acid-consuming material developed in the course of the mining operation. In either case, the objective is to mix sufficient acid consuming material into the waste pile to uniformly offset acid generation in the waste. In the event that acid-consuming materials are economically available, this approach offers the ideal preventative concept in that long-term stability of the wastes can be assured.

In coal stripping operations, the blending approach can be attractive because the required acid-consuming material is often available onsite and must be stripped and relocated as an integral function of the mining operation. However, this opportunity is seldom available at base metal hard rock mines despite the fact that the characteristics of waste rock can vary from zone to zone within a given mining operation. The cost of mixing offsite neutralizing materials into acid waste rock has been shown to be prohibitive (Nolan, Davis & Associates Ltd., 1987).

Underwater Disposal

This concept can include disposal into natural water bodies, flooded mine workings, or specifically designed retention systems. There is a steadily accumulating volume of field evidence that disposal of reactive mine wastes underwater curtails oxidation to virtually zero levels due to the very low diffusivity of oxygen through water (approx. 2×10^{-6} cm/sec). Shortcomings to this approach include the fact that relatively few metal mines are located within economic haulage distances of suitable natural bodies of water; the concern over the physical impact of waste rock disposal on benthic conditions of a lake or coastal marine environment; and the fact that the long-term effects of lake turnover, natural diffusion of oxygen through water, and the influence of benthic organisms are not as yet well understood.

The opportunity for acid waste rock disposal in flooded open pits is very mine specific and will seldom offer a total solution to the problem due to the added volume of waste caused by swell (often about 30 percent); the fact that open pits will seldom flood back to the surface level, and the economic implications of moving waste back into the pit. However, in many instances, backfilling will provide an attractive means to reduce the volume of wastes requiring other management measures.

It is generally recognized that a fluctuating water level within reactive waste material is a worst possible situation in that conditions in the wetted zone are ideal for the generation of acid and flushing of the reaction products. Thus, where pits are to be filled above and below the water table, it is essential that the range of water fluctuation be defined and a layer of nonreactive material placed in this zone so as to avoid the fluctuation of water through acid-generating wastes.

The practicality of providing engineered underwater disposal systems for acid waste rock should be evaluated with respect to the cost of providing very large subaqueous storage volumes and concerns over the long-term safety and stability of manmade retaining systems.

Use as Underground Mining Backfill

In circumstances where acid waste rock exists in close proximity to an underground mining operation, the possiblity of using it as mine backfill can be considered. Normally preferred criteria for mine backfill are as follows:

- nonreactive, nonfriable
- minus 15 cm size range
- minimum transportation costs

The use of reactive acid rock as backfill is a compromise from the mining standpoint as it can lead not only to the generation of highly contaminated acid drainage within the mine, but also to the possiblity of an uncontrollable exothermic reaction within the backfill. This has occurred at several metal mines in Canada including the Brunswick No. 12 Mine in New Brunswick and the Sullivan Mine in British Columbia.

Waste Pile Sealing Techniques

To be totally effective, any sealing system for AWR storage systems must eliminate the throughput of moisture and reduce oxygen levels within the system to less than 0.5 mg/L. In principle, this would require the following:

(1) Top cover to prevent the infiltration of rainfall and air diffusion.

(2) Sideslope cover to prevent rainfall infiltration, air diffusion, and induction.

(3) Stabilization of top and side covers to prevent wind and water erosion.

(4) Prevention of penetration of the cover by roots, animals, traffic, etc.

To date there are no recorded cases of totally effective sealing sytems for acid waste rock dumps. The best documented case is the previously mentioned Rum Jungle pyritic waste piles in Northern Australia, but even there the long-term effectiveness of the cover is open to question.

The advantages and disadvantages of various cover materials are described in table 2. Composite covers designed to prevent the desecation of clay or till would be expensive, but may warrant further investigation. An example might consist of the following:

Table 2.--Alternative cover materials for waste rock dumps (depending on local availability).

Cover Material	Permeability to Water (m/sec)	Advantages/Disadvantages
Compacted clay	10^{-9} - 10^{-11}	Large quantities problematic in many areas. Subject to erosion, cracking, and root penetration. Good sealing if protected and maintained.
Compacted till	10^{-7} - 10^{-9}	As above, but generally more permeable.
Compacted topsoil	10^{-5} - 10^{-8}	As above, but less robust, more permeable. Questionable longevity.
Peatland bog	10^{-5} - 10^{-6}	Need to maintain in saturated condition. Normally impractical for elevated waste dumps and side-slopes.
Concrete	10^{-10} - 10^{-12}	Subject to cracking, frost, and mechanical damage.
Asphalt	10^{-20}	As above.
HDPE synthetic cover	Impermable	Requires proper bedding and protective cover. Highly impermeable. Lifespan unlikely to exceed 100 years. Subject to root and mechanical penetration.

surface vegetation--stabilize surface/ aesthetics 20 cm

topsoil--prevents desiccation of clay 20-30 cm

coarse material--root barrier 50-200 cm

clay/till--provides saturated seal 20-30 cm

coarse material--capillary break

The risk and implications of cover failure can be reduced by providing a series of seals throughout the dump through the use of cellular construction as described by Bell (1987). This approach, shown diagramatically in figure 2, not only limits the implications of local failures in the surface seal, but also allows control to be exercised over the rate of oxidation by the application of bactericides or other means as the dump is constructed. This is an extremely important consideration bearing in mind that the life of a mine can extend over several decades and that the oxidation process will start in the waste as soon as it is exposed.

Bactericides and Inhibitors

In field trials on coal spoils sodium lauryl sulphate has been used successfully with the beneficial effects lasting up to 6 years if applied in the form of rubber matrix pellets (Sobek 1987). However, trials of its effectiveness on hard rock wastes currently indicate difficulties in saturating the surface of the waste rock throughout the potential reaction zone. Despite these difficulties, it appears that SLS or other reagents may prove of value for controlling the biological rate of oxidation in acid waste rock dumps as long as it is used in a preventative manner before extreme acid conditions become established and prior to applying more permanent control measures. As previously mentioned, its use in association with cellular dump construction may, for example, prove advantageous.

Passive Treatment

With the possible exception of underwater disposal, none of the previously discussed methods of managing waste rock have proven to be totally effective in preventing the formation of contaminated leachate. The need to provide downstream treatment is therefore likely to persist. A number of wetlands have been established in the Eastern U.S. coal regions to provide passive treatment of acid drainage (Pesavento 1987, Kalin and Everdingen 1987). Experimental work on passive treatment methods is being undertaken at a number of mine sites in Canada with a view to evaluating the effectiveness of these systems under Canadian conditions and with respect to their ability to handle peak flows and high concentrations of metals under long-term stress conditions.

Conventional Treatment Systems

At the present time, collection and treatment of acid drainage is the primary means of controlling contaminated leachates from acid waste rock dumps. The cost of maintaining such systems in perpetuity as well as the implications of treatment sludge disposal are well recognized. The technology for AMD treatment is well established and described extensively in the literature (e.g., Monenco 1986, Vachon et al. 1987)

Other potential methods for AWR management that have been identified include the creation of anaerobic conditions by incorporating organic material into the dump, integrated disposal of AWR with mine tailings to reduce air diffusion into the waste rock, segregation of acid-producing material to reduce the volume requiring special measures, and milling of reactive rock in situations where the recovery of metal values and reduced long-term management costs might offset the cost of processing. All of those methods require further evaluation before their effectiveness or practicality can be fully assessed.

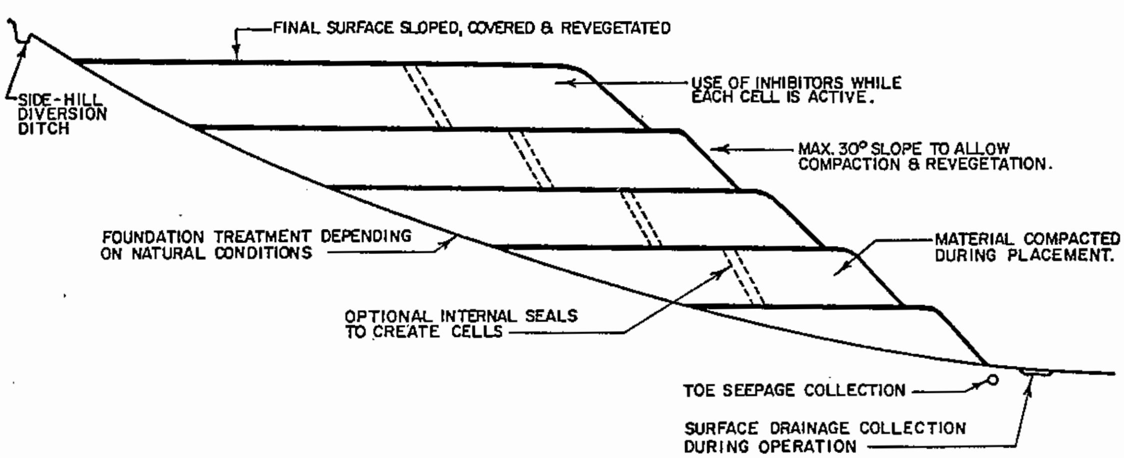

FIGURE 2 - CONCEPTUAL CROSS-SECTION OF CELLULAR CONSTRUCTED DUMP

AFTER BELL, 1987

RESEARCH RECOMMENDATIONS

The following categories of applied research were identified in the Acid Waste Rock Study:

(1) Investigation into acid generation mechanisms in AWR including effect of various dump parameters; relative roles of oxygen diffusion, convection and trapped air, and bacterial mechanisms in force as internal dump temperatures increase.

(2) Development and calibration of acid generation predictive techniques for AWR.

(3) Investigations into AWR management methods including:

- long-term effectiveness and potential impact of underwater disposal
- effectiveness of cellular construction techniques
- definition of the permeability, air diffusivity, and longevity of various waste dump cover materials and then effectiveness in controlling acid generation
- use of bactericides and inhibitors on AWR dumps
- development of criteria for the use of AWR as mine backfill
- creation of anoxic conditions in AWR dumps through use of organic methods

(4) Evaluation of passive treatment alternatives, including wetlands, for AWR dump leachates.

(5) Case studies at operating mines to define alternative AWR management strategies and their implications to production economics and lifetime costs.

These recommendations have now been integrated into the national Reactive Acid Tailings (RATS) Program.

CONCLUSIONS

1. Preventative management methods for controlling the generation of acid in sulphidic waste rock at base metal mines in Canada and elsewhere are in their infancy.

2. There is no proven method of AWR management for which backup leachate collection and treatment is not required in most circumstances, with the possible exception of underwater disposal.

3. The effectiveness of passive treatment systems to handle residual leachate flows is unproven in Canadian conditions.

4. Knowledge does exist to site and design AWR dumps so as to minimize the generation of contaminated leachates. Well-constructed covers and seals can be effective in this regard although some ongoing maintenance will likely be required in most circumstances. Evaluation of alternative systems under field conditions is required.

5. Use of sealed waste dumps constructed on a cellular basis appears to have promise as does underwater disposal in natural waters or manmade systems. These approaches should be further evaluated.

6. The ability to predict the extent and form of acid generation in AWR is important to the selection and design of management systems as well as to the assessment of long-term mining costs.

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