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Environmental Issues and Eco-Based Mine Planning

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ABSTRACT: The activities of mining unavoidably have impact on the environment while providing invaluable resources to our standard of living. Since human beings cannot survive without the mining industry what we should do is to minimize its environmental effects and make it a more sustainable enterprise. In this article we would like to discuss major environmental challenges related to mining industry and especially concentrate on how to deal with and minimize acid mine drainage generation through careful mine planning. The International Law regulating environmental issues related to mining will also be briefly discussed.

1 INTRODUCTION

Mining is an essential activity that provides the raw materials for our industrialized society. However, unless adequate precautions are taken, mining can be accompanied by serious negative impacts on the environment, on human health and on the immediate community. With modern practices, many of these effects can be avoided, or at least greatly reduced. Much of the negative impact can be minimized through careful project planning, choice of appropriate mining technologies, and careful ongoing operation.

Unless preventive measures are taken mining can cause changes in landscapes, water tables and animal habitats, as well as air and water pollution, and permanent degradation of land. Toxic chemicals, dusts, heat and noise can seriously affect the health of workers and community. Impacts may occur from mining itself or from ancillary operations such as transport, laboratories, etc. Potential environmental impact, including pollution effects, which may arise from poorly planned and operated mines are summarized below:

- Solid waste disposal
- Acid Mine Drainage (AMD)
- Cyanide & heavy metals contamination
- Air pollution

Each of these pollution types has a different significance and the effect and the amount of pollution generated depends mainly on mining and processing technology applied among other parameters. Each stage of mine planning such as:

- Exploration
- Project development
- Mine operation
- Mine processing
- Transport and storage, and
- Mine closure

can also have different environmental impacts and all of them should be considered separately.

It is paramount importance to deal with and address the potential of water and soil pollution due to mining at a very early stage of a mining activity in order to avoid serious potential of a future pollution. Therefore while trying to treat the present pollution in an ecologically and economically effective way we should also find some prevention measures before bringing any new mining project into operation.

Apart from being an environmentalist or believing the importance of willingness, there are some other reasons to consider environmental issues in mining projects. For example, we can increase profitability of a given project with a good environmental management plan. Also we need to emphasize that getting financing from any monetary organization requires a detailed Environmental Impact Assessment (EIA). The other reason to prepare a detailed EIA is to comply with the continuously stringent national or international laws and regulations.

As we have mentioned earlier due to quantity constraints we are going to address the issues related to Acid Mine Drainage (AMD) in this paper.

2 ACID MINE DRAINGE (AMD)

Following information about acid mine drainage was reiterated from MEND Manual Volume 4 (Tremblay & Hogan, 2001).

In many mining operations, especially base metal, precious metal, uranium, diamond and coal mines, it is common to encounter sulphide minerals both in the mined ore and in the surrounding rock. When these sulphide minerals, particularly pyrite and pyrıhotıte. are exposed to oxygen and oxidize to sulfite and the oxidi/ed minerals subjected to any water will create acidic mine drainage unless sufficient acid-neutralizing minerals such as calcite are present. The acidic mine water may contain elevated concentrations of metals and salts. These metal elements can include many of the typical major rock constituents (Ca, Mg. K, Na, AI, Fe, Mn) as well as trace heavy elements such as Zn, Cu. Cd, Pb, Co, Ni, As, Sb and Se

On the surface, rainfall and snowmell Hush leachate from the waste sites with reduced pH values. II this acidic drainage left uncontrolled and untreated, the drainage can contaminate water streams and groundwater, affecting negatively all aspects of life. What complicates the issue is that depending on the iron sulphide and carbonate content of the minerals the acid irunc drainage may be generated within few days perhaps years or decades after the exposure.

There are numerous examples of acid mine drainage throughout the world where elevated concentrations of metals in mine drainage have adverse effects on aquatic resources and prevent the reclamation on mine land.

The treatment of acidic mine drainage and/or the ecological damage and lost revenue due to unusable land 01 watei resources create huge liability and result in huge lost revenues. For example in North America acidic drainage has resulted in significant ecological damage and multimillion-dollar cleanup costs for industry and governments. Table I shows some liabilities for Acid Mine Drainage.

Table I. Liability for Acid Mine Drainage

Location	Refeience	Estimated liability (US$>
Leadulle Coloi.ido USA	USEPA	290 million
Suinmilville. Coloiado. USA	USEPA	175 million
Abandoned Mine Land«, Wyoming USA	Richmond. 1995	>25? million (have been spent)
An updating Mine. Utah. USA	Muney et al. 1995	500-1200 million
557.01)0 abandoned mines in 32 slates USA	Tiemhlay & Hegau. 2001	32-72 billion
"iiistiaha	Haines 1997; Gustatsson 1997	900 million
Sweden	Haines. 1997. Gustatsson 1997	300 million
Canada	Tiemhlav & Hoiran, 2001	1 9-5.3 billion

Based on these data, after including other sites not shown here (Europe. South America, Africa), the total worldwide liability is estimated to be around US$100 billion (Tremblay & Hogan, 2001). Finding the appropriate prevention and control measures to prevent the creation of acidic mine drainage not only ecologically but also in financially is a huge enterprise.

3 ENVIRONMENTAL LEGISLATION ON AMD

The environmental issues were first introduced into world environmental conscious agenda mainly after the World Environment Summit of Stockholm in 1972. On this summit the participant probably at the first time described a new terminology, the definition of sustainable development. Namely, the sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition at least in appearance addressed mostly the environmental issues and did not addressed the equally important social issues. This is the probable explanation that countries started to develop or enhance their own environmental regulations aligned with the new international environmental laws. Among these regulations the Environmental Impact Assessment (EIA) is the one what gained the strongest momentum what most directly affecting the industries in a large extend the mining industry. Although there are some differences in application of EIA procedures in each country, the main idea is to define all possible environmental impacts and their prevention measures before a company can get permit for any operation. Especially countries having significant acid mine drainage problem have changed their mining permit procedures and required to submit detailed information to be used to access the site's potential for generating AMD due to the mining activity.

In the USA, standards and rules related to AMD issue is regulated by Environmental Protection Agency (EPA) throughout the United States. Although there are some differences between the different environmental regulations related to AMD the basic requirement set by the Environmental Protection Agency (EPA) assures communality in the requirement through the entire United States. The EPA's set baseline limitations and regulations, which can be found in 40 CFR, Part 434. Also the National Pollution Discharge Elimination System (NPDES) include water quality standards. These regulations define minimum effluent concentrations from the Acid Mine Drainage plant which are normally applied in AMD design and treatment systems (http://www.cee.vt.edu/program-areas/envi ronmenlal/teach/awprimer/grouD 19/section-3.htm)

The additional requirements on AMD in USA resulted in a decrease for new mine permits. In some states tor example in Pennsylvania the introduction of a new amendment to the Clean Streams Law requiring mine operators to treat mine drainage resulted in a significant drop for permit application since 1984. In addition to the treatment requirement, the law requires that the mine operator should demonstrate lhat the mining would not create water quality problems on a long term (http://www.dep.state.pa.us/dep/deputate/minres/districts/AMDPostMortem.htm).

Another example can be given from South Dakota where mining is regulated through the South Dakota Mined Land Reclamation Act (SD Codified Law, SDCL 45-6B) and the South Dakota Mined Land Reclamation Regulations (Administrative Rules of South Dakota, ARSD 74:29). South Dakota's mining laws attempt to strike a balance between economic development and environmental protection by promoting mining as an industry while requiring 1) pollution prevention and 2) reclamation of affected lands to a level usable for alternative land usage. The trust of this law is a multi-media (contaminant) permitting approach that requires all critical pollutant should be monitored and controlled. This regulatory approach stresses the importance of AMD prevention from the start of operations using improved predictive capabilities (Durkin et al, 1998).

Having reviewed a number of similar examples from different states suggests that probably the stale of California has the strictest environmental regulations within United States.

It is probably safe to say that countries, which have had already serious AMD problems, introduced the strictest regulations. Among these countries are, the USA, Canada and Australia who are applying strict standards for AMD. The introduction of the Metal Mining Effluent Regulation in 2002. Canada probably set the highest standard. These new rules were developed through consultations with the mining industry, environmental organizations, native land users, and provincial and territorial governments.

AMD is also considered as an important issue for international monetary organizations such as World Bank. According to World Bank Operational Policies (OP 4.01: Environmental Assessment) any mining project can only be funded after scientific proof of prediction, prevention and treatment measures of acid mine drainage. In addition to the AMD issues, the International Finance Corporation (IFC) that is the largest multilateral source of loan and equity financing tor private sector projects in the developing world recently changed their practices and now they want to ensure that their investments are environmentally and socially sound. This demxinstrates a positive development and assessment of more complex impact due to mining activity beyond the economic growth criteria.

4 ACID MINE DRAINAGE TREATMENT

Although, there are many successful techniques to treat acid mine drainage, the importance of this topic is providing the need for further research for new alternatives. In the following we list the three main techniques most frequently used for AMD treatment.

Active treatment methods:

1. Chemical treatment
2. Metal recovery

Passive treatment methods:

1. Anoxic limestone drainage systems
2. Aerobic wetland treatment systems
3. Passive anaerobic treatment systems
4. Biosorption treatment methods
5. Passive *in-sim* treatment methods

Hybrid active/passive treatment systems

In order to chose the best treatment alternative several parameters such as. geochemistry, hydrology, cost, the experience of the operator, technical and operational limitations, etc. should be considered. The last couple of decades provides many good as well as bed examples of different AMD treatment techniques. In the present practice the mine operator can develop a much better mid reliable AMD treatment techniques by carefully analyzing and studying and learning from the previous bed experiences. This analysis can be easily done because there are many documents giving Ihe technical and practical details of each conventional and innovative technique.

5 PREVENTION AND CONTROL OF AMD

Prevention and control techniques included in this cuticle were directly reiterated from MEND Manual Volume 4 (Tremblay & Hogan. 2001).

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cics (OP 4.01 : Environmental Assessment) any mining project can only be funded alter .scientific proof of prediction, prevention and treatment measures of acid mine drainage.

In the following we described a few acid mine drainage prevention techniques what applied and can be considered for specific site. There are several techniques can be applied to prevent acid mine drainage. Followings are most commons:

5. / Water covers

This technology based on that the oxidation of sulphide minerals can be inhibited by the presence of a water cover, as the water acts as a barrier to the diffusion of oxygen from the atmosphere to the submerged sulphides. Potential disposal options include; (1) the subaqueous disposal of unoxidized sulphidic wastes under a water cover; (2) and Hooding of oxidized wastes.

Water covers have been applied at many sites, such as Quirke (Ontario) and Solbec (Quebec), but arc not universally applicable. Related issues such as the ability to maintain a water cover over the long-term, the integrity of the containment structures, locality and site-specific potential risks due to seismic events, severe storm events, etc. can negate the use of this technology. However, under suitable conditions, the present state of knowledge is sufficient to allow for the responsible design, operation and closure of waste management facilities using water covers for both fresh and oxidized tailings and waste (Tremblay & Hogan, 2001).

Estimated cost for self-sustained water cover is changing between $75,000-$370,000 depending on the site-specific properties. The highest estimated unit cost is based on a scenario where the site is poorly suited for a water cover (Tremblay & Hogan, 2001).

5.2 Dry covers

The key objective for dry cover systems is to provide a barrier that minimizes the influx of atmospheric oxygen to the mine waste, and to limit moisture infiltration. Apart from these functions, dry covers are also expected to be resistant to erosion, and provide a media for vegetation.

Dry covers can range from a single layer of earthen material to several layers of different material types, including native soils, non-reactive tailings and/or waste rock, geosynthetic materials, and oxygen consuming materials. Multi-layer cover systems utilize the capillary barrier concept to keep one (or more) of its layers near saturation under all climatic conditions. This creates a blanket of water over the reactive waste material, which reduces the influx of atmospheric oxygen and subsequent production of acidic drainage.

Use of alternate cover materials such as sulphide-free tailings and organic waste materials, instead of natural soils can make this technique more challenging and cost effective. Especially the use of low cost waste materials from other industries such as, crude compost, lime stabilized sewage sludge, paper mill sludge would make it possible to use one waste to solve a problem of another waste.

Dry cover systems are commonly used to decommission waste rock piles and tailings impoundments at sites around the world. Barrick's tailings site in Northwest Quebec, provided the first full-scale demonstration project of using tailings in a cover system (Tremblay & Hogan, 2001).

The unit cost for construction of a dry cover system is extremely site-specific. It is difficult to develop an average value because of the impact of the various components that influence cost. For example, the Equity Silver mine cover system (0.5 m compacted til! and 0.3 m non-compacted till) was constructed for approximately $35,000 (CAD) per ha (including reshaping, etc.) (Aziz & Ferguson 1997). The borrow area for the till cover material was immediately adjacent to the waste rock piles at the Equity site and large mbber tired scrapers were used to pick up and place the till. Hence, the cost for construction of the cover system was minimal when coupled with the sound site construction management that occurred. A similar cover system at another site might cost twice or three times more per unit area if the cover material borrow is at a greater distance and truck and shovel/backhoe construction technique needs to be used. The Rum Jungle waste rock cover system in Australia was constructed over 51 ha area for approximately $67,000 (AUD) per ha (ineludins reshaping, etc.) (Tremblay & Hogan, 2001).

5.3 Saliiration

Saturation refers to the moisture saturation of tailings pore spaces to make good use of the low rate of oxygen diffusion through water-filled pore spaces in comparison to those that are gas-filled. Saturation can be achieved by elevating the water tables in tailings. An elevated table by itself does not prevent acid generation, as there may be zones of near-surface exposed and drained tailings that remains available for oxidation. The use of an elevated water table can, however, significantly reduce the inventory of .sulphide tailings available for oxidation. The use of elevated water table concept may be cost advantageous when applied in tandem with other approaches to prevent and control acid generation. The saturation of pore spaces in waste rock piles as a means of controlling acid generation is normally not an option.

There are some applications of saturation techniques in Canada and Australia. Site-specific conditions determine the suitability of this technique. Closure costs indicate that elevated water table technique", when suitable, can provide significant closure cost savings in comparison to collection and treatment, and the use of an engineered dry cover.

5.4 Separation and Segregation

Key driver in separation and segregation is to identify techniques to separate sulphide solids for disposal, or produce reduced sulphur content tailings for use in site rehabilitation. Laboratory and field tests show that depyritized tailings have excellent potential for use in dry covers. Flotation has been shown to be an effective, less costly, method of reducing the sulphide content of tailings prior to their discharge. The quantity of sulphide minerals that would need to be segregated and removed using mineral processing techniques is dependent on the characteristics of the tailings and as such this aspect needs to be assessed on a site-specific basis. Economic analyses are subject to variation due to the specific characteristics of the tailings, the depyritization process, and the low-sulphur tailings application. The estimated unit cost for depyritization at an operating mill is expected to be in the range of \$0.35/t for non-cyanide tailings, and about \$0.60/t tor cyanide tailings (Tremblay & Hogan, 2001).

5.5 *Permafrost unci freezing*

Permafrost and freezing is an area of continuing and evolving research for cold climatic conditions to inhibit acid generation. Sulphide oxidation rate slows considerably as the temperature of the waste drops and approaches 0 °C. Permafrost forms is present across Northern Canada and covers about 40% of the country land mass. A reasonable and sufficient knowledge base exists with regards to the construction of a variety of structures over permafrost. However, knowledge and experience in the use of permafrost, including the natural and assisted freezing of sulphide wastes, is an area that continues to be developed.

5.6 *Backfilling (in-pit) and co-disposal*

The backfilling of mine openings, both open pits and underground workings, has been practiced extensively internationally. It is only recently, however, that pit backfilling programs have been designed for the disposal of sulphide tailings and waste rock with mine closure in mind. As a result, some mine openings that may have previously been considered a legacy may be beneficially used for mine waste disposal.

The key objective in placing sulphide wastes in a mined-out pit is to provide a suitable physical and geochemical environment to prevent acid generation and thereby reduce adverse impacts to receiving groundwater and surface water resources. The level of engineered controls that are required to prevent acid generation can be determined to a large extent by predicting the future quality of the pore water within the wastes. The degree *of* oxidation of the wastes to be disposed in a pit will determine the stability of an in-pit disposal program, and significantly influence the design of the in-pit disposal program. The quality of the pore water in the disposed wastes may vary over time. In some cases, the initial rates of contaminant release will be high, and then reduce as the leachable fraction *of* the waste declines, possibility to levels where the potential for environmental impacts is negligible. Conventional testing (i.e. pore water sampling, sequential leaching tests, humidity cells) can be used to predict pore water characteristics, leachable fractions, and ultimate concentrations of contaminants.

While backfilling has been extensively applied and there is a sound technical base for in-pit disposal programs, few sites provide scientific databases that can be used to assess the performance of these technologies.

Backfilling can provide significant cost saving in comparison to other closure operations for tailings and waste rock. This technique can also be cost advantageous for the disposal of historic wastes, provided conditions are suitable. The application of backfilling is, of course, subject to site-specific conditions and regulatory review, and as such these programs need to have well founded technical and environmental bases (Tremblay & Hogan, 2001).

5.7 *Blending and Layering*

The blending and layering of waste rock is an approach that is founded on the geochemistry of sulphide oxidation. In concept, a net acid generating waste could be blended with, or layered between, alkaline materials to produce a non-acid generating waste that has seepage water quality acceptable for discharge without additional measures. This is a challenging area that continues to be under development given the potential benefits.

Major factors should be considered when designing a blended waste rock dump are; mineralogy and reaction kinetics; relative proportions of the acid generating (AP) and acid consuming (NP) rock types, and resulting overall NP/AP ratio; proximity and arrangement of acid generating and acid consuming materials; orebody geometry and mining plan; construction methods; hydrogeology of the waste rock dump; and operational commitment and monitoring. The second factor is probably one of the most significant factors affecting the degree to which blending can achieve the objectives.

There are very few well-documented examples of waste rock blending. Coal mines in the Appalachian region of the eastern USA have used waste rock blending, however, it was found that other control measures were often applied and these prevented evaluation of the success of blending. Many examples of older hard rock mine waste rock dumps with non-acidic drainage are known, but the source characteristics are not adequately understood. Recently, waste rock dumps have been characterized during construction, but the monitoring records are not yet sufficient to evaluate blending. A significant issue is the question of how long the drainage must be monitored before blending can be judged successful.

Waste rock blending can significantly increase the cost of waste handling due to stricter scheduling requirements, the potential requirement to re-handle wastes, greater personnel requirements for monitoring, and analytical costs for blast hole cutting analysis. Including waste rock characteristics during scheduling can simply minimize this cost. This new approach is called "eco-based scheduling'* and explained below.

6 ECO-BASED STRATEGIC MINE PLANNING

Bearing in mind that it is always easy and less expensive to prevent any pollution then to solve if after being created, researches were concentrated on promising prevention techniques such as layering and blending ihrough strategic mine planning.

In eco-based scheduling the physical layout of an open pit mine, and the locations of open pit mine waste disposal areas, are planned in advance of ore mining and waste stripping operations. The pit planning process focuses on optimizing the profitable extraction of ore in a safe and environmentally responsible manner. In concept, the economic value of a tone of ore must be greater than the cumulative costs associated with the mining and processing of that tone of ore, plus any other costs associated with the stripping and disposal of perhaps several tones of mine waste per tone of ore.

Economic evaluations of open pits at the planning stage are typically used to develop a cut-off grade, which is the minimum grade of ore that can be mined profitably or, in some cases, to breakeven. The cut-off grade is different for each open pit mine and is a function of the anticipated revenues and costs. The cut-off grade and the physical limits of an open pit mine are, therefore, sensitive lo changes in revenue (e.g. metal price fluctuations) and costs (i.e. mining, processing, taxes, mine decommissioning, etc.).

At most new open pit mines, the potential for acidic drainage is determined early in the planning process. A decision can be made at the planning stage to segregate reactive wastes and relocate the wastes to the open pit or locate properly according to layering or blending technique once it is mined out. In such a case, the economic evaluation of the open pit and the pit design would take into consideration all anticipated costs to implement an in-pit disposal or layering/blending program.

In this concept, all the rock types with acid generating potential are identified and tagged within the block model. The strategic mine planning and scheduling program is constraint such that the best open pit schedule is obtained by balancing profit maximization objective with controlled production of acid generating rock. To accomplish this, operational research based pit scheduling techniques like CSM-LP can effectively be used (Dagdelen et al, 2002).

7 CONCLUSION

In many mining operations, especially base metal, precious metal, uranium, diamond and coal mines, it is common to encounter sulphide minerals both in the mined ore and in the surrounding rock. When these sulphide minerals, particularly pyrite and pyrrhotite, are exposed to oxygen and oxidize to sulfite and the oxidized minerals subjected to any water will create acidic mine drainage (AMD). International Laws regulate discharge of AMD. International Financial institutions does nol allow financing of a given projects unless they provide scientific proof of prediction, prevention and treatment measures of acid mine drainage. Although a lot of effort is being spent on treatment and prevention of AMD, we believe there is still significant work to be done for reduction and prevention of AMD through eco-based strategic mine planning practices.

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