DESIGN OF A TAILING LINER AND COVER TO MITIGATE POTENTIAL ACID ROCK DRAINAGE: A GEOCHEMICAL ENGINEERING PROJECT[1]

Thomas Wildeman[2], James J. Gusek[3], Donald R. East[3], and Adriaan de Villiers[3]

Abstract: In design for closure of a mining facility, both the physical and chemical factors that lead to the desired result should be taken into account. In mining operations, this usually entails flow of water through rocks, soils, or tailing material and chemical reactions of these solid materials with the water. Design and problem solving associated with water - rock - soil interactions can be considered geochemical engineering. These principles were applied to the recent design of a tailing facility to be placed in a mountainous region of western United States where there is an excess of net precipitation. Because the tailing material gave all indications that it would be acid producing, the design issue was to build the facility and reclamation cap to eliminate oxidation and thereby mitigate potential acid production by sulfide minerals. It was assumed that some small amount of underdrainage would occur and the liner design emphasized complete collection of this water and discharge through the foot of the dam into a monitoring sump. Special considerations in the design of the geomembrane liner included providing a cushion for construction equipment, and protection from damage by freezing and UV radiation. Because the underdrain water may require some treatment, special provisions were made to separate the water flowing across the tailing system from that flowing from the underdrain. Operation and closure of the facility is based on subaqueous deposition and storage. The reclamation cap design maintains saturated tailing without a permanent lake. Rather, a permanent water table is maintained near surface and above the tailing, within the multi-layered reclamation cap. To affect surface runoff, a mild sloping final surface was designed with a wetland along the center of the facility for flow control. The water level would be maintained above an organic rich soil layer that would facilitate removal of all dissolved oxygen. Careful control of the hydraulic conductivity of the soil layers in the reclamation cap will help to maintain greater flow of direct precipitation and run-on from an adjacent hillside across the cap instead of vertical flow through the tailings. What little water that does reach the tailings will geochemically interact with the reclamation cap soils such that all oxygen is removed. Acid production from the tailings would thus be minimized.

Additional Key Words: tailing closure, subaqueous closure, sulfidic ores

Geochemical Engineering

To understand geochemical engineering, it is useful to establish the distinction between science and engineering. A simplified explanation based on what people do is that scientists ask and answer questions and engineers solve problems or design products, structures, processes, or systems. In this context, geochemical engineering applies chemistry to design and problem solving situations related to earth structures or processes involving earth structures. Based on this definition, geochemical engineering is obviously related to geological engineering, mineral process engineering, environmental engineering, and mining engineering.

Because of this relationship with so many other fields, the idea of using geochemical engineering in this paper is not a promotion for a new field, but more a call for people in existing fields of engineering to expand their knowledge base for design and problem solving. Besides dealing with earth structures, there do appear to be other elements essential to this area of engineering. First, water is present and usually

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flowing through or around the structure. Second, chemistry is involved in the extraction, treatment, or passivation of some natural resource that is in contact with the water.

Besides these essential elements, there are other aspects of this field that often describe the problem or design issue. Because earth structures are involved, there are often inherent co-dependencies and ambiguities in the project that have to be considered. This ambiguity is particularly true when the project involves the design of some process. In other areas of process engineering, complete control of the situation is assumed to be an essential to design. Also, geochemically engineered controls often feature passive rather than active methods in the solution to the problem or design assignment. Originally, design concentrated on structures that treated water problems after the problem occurred. However, design projects are now building geochemical features into structures for prevention of future environmental problems.

Another facet of geochemical engineering is the use of earth structures to remove contaminants from water. Common applications include designing overland deposition and soil attenuation systems, treatment of mine drainage, and treatment of contaminated ground waters. In this category, the development of anoxic limestone drains (Brodie, et al., 1991) and constructed wetlands (Filas and Wildeman, 1992, Wildeman, Brodie, and Gusek, 1993, Wildeman, et al., 1994) for treatment of mine waters are good examples of geochemical engineering.

In the area of passivation, the geochemical goal is to precondition water so that when it flows through a structure such as a waste rock pile, reactions that could release contaminants will not occur. Here, examples are not as prevalent. One recent passivation project was published by Nawrot and others in 1994. The problem to solve was the abatement of acid seeps from a buried acid gob pile in a coal field in southern Illinois. Alkaline recharge pools were constructed above the buried seeps to raise the pH of the water that flowed through the gob piles. The geochemical basis for passivation was that if the pH of the water flowing through the pile can be maintained above 5, then bacterial catalysis of the oxidation of pyrite will be substantially reduced (Nawrot and others 1994).

This paper describes another design project that deals with passivation of water to keep it from reacting with tailings that have a high probability of generating acidic solutions. The geochemical principles needed for design as well as how they are applied to the design are described.

The Design Project

As part of the plan for a mining development in western United States, the need arose for the long-term storage of acid-producing mine waste and tailings. The mine site is in a mountainous region of high environmental sensitivity where an excess of net precipitation historically occurs. The tailing facility is planned as a side-valley impoundment around which an existing creek is permanently realigned. The realigned creek is excavated through high quality bedrock of long term stability.

Acid production and acid neutralization tests on tailings, waste rock, and construction materials revealed that there were definite amounts of acid producing tailings and mine waste. Physical tests performed on the tailings material fortunately showed that tailings consolidation will be sufficient to support construction equipment even if subaqueous deposition is used. Hydraulic conductivity measurements gave indications of how water will flow through all the materials. Using this information, the assignment was to design a tailing facility so that ground and surface water flow would be controlled during facility operation and so that the facility could be closed and reclaimed such that acid rock drainage is minimized. This paper focuses on the design of the liner and reclamation cap, the key geochemically-engineered features of the facility.

Design of the Liner

In the design of the liner, it was assumed that some underdrainage would occur and the primary objective was control of the chemistry and amount of underdrain flow. With this objective, the first issue was to isolate the tailings from the existing creek. This will be done by creating a permanent and stable diversion of the creek such that it remains the lowest feature in a cross section of the valley. To collect underdrain water, a pipe gallery was placed below the liner. The liner system has to serve the following needs:

1. Minimize the quantity of water that reached the underdrain.
2. Protect the water barrier from UV radiation and freezing and thawing.
3. Allow construction vehicles to have temporary access to the floor of the facility.

To meet all these needs, a composite liner system was designed.

A schematic diagram of the composite liner is shown in Figure 1. The water barrier will be 60 mil high density polyethylene (HDPE) placed over a 30 cm (12 in) layer of low permeability soil. A 45 cm (1.5 ft) thick cushion layer of minus 5 cm (2 in) screened material directly overlies the HOPE liner, primarily to protect the liner from construction and to provide UV radiation protection. A further 1.0 m-thick course protective layer, consisting of minus 15 cm pre-production waste rock, is placed over the cushion layer. This layer protects against wave and ice damage and larger vehicular loads.

Most all of this design was based on the physical properties of the liner and protective layers. However, geochemical engineering influenced the liner design with respect to how closure of the tailing facility would be managed. The pre-production waste rock, which is the upper most protective layer, is material that may eventually be acid producing if left exposed to the atmosphere. It was decided to immediately dispose of it by using it in the liner design. The tailings are also potentially acid producing. Such a decision is reasonable if this material and the tailings can be permanently isolated from the atmosphere when the tailing facility is finally reclaimed. To do this, an investigation of geochemical principles is necessary.

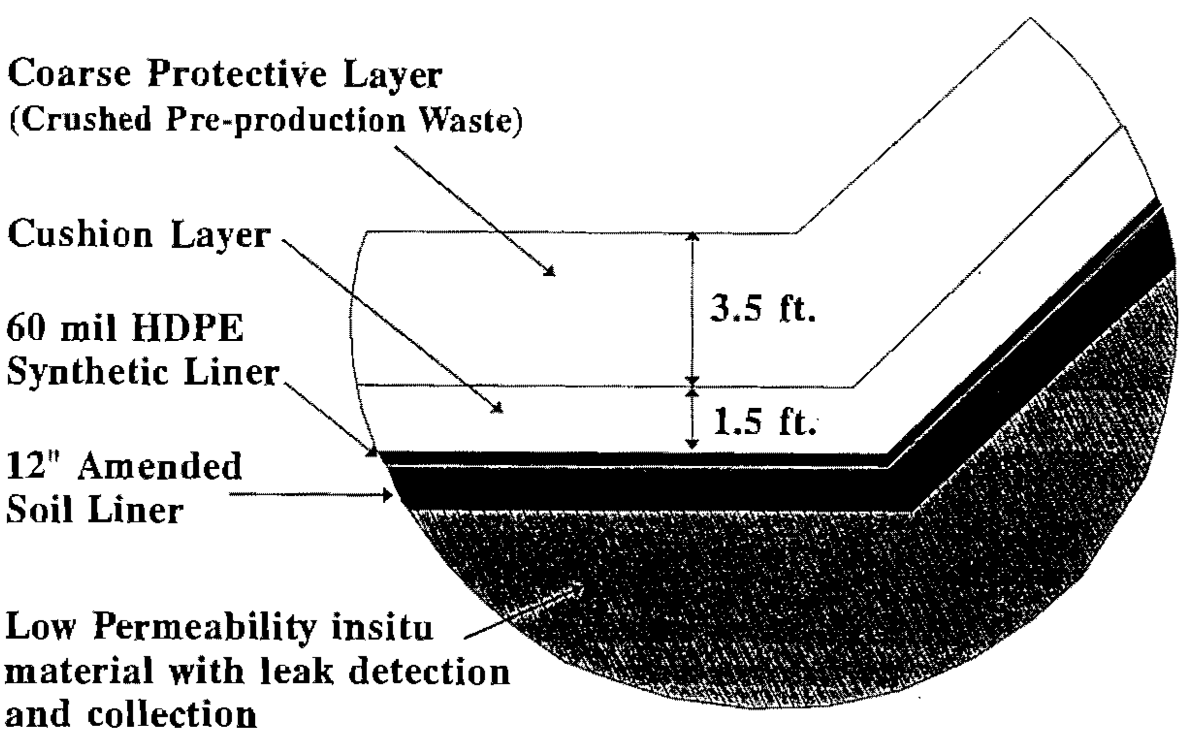

Figure 1. Schematic diagram of the composite liner.

Geochemical Considerations

A more complete review of the geologic and geomicrobiologic principles behind the design of the reclamation cap is given by East and others (1994). The conclusions in this review are:

1. The final closed system is similar to a sedimentary ore deposit. Investigations of these deposits show that base metals exist as sulfides, carbonates, and hydroxides.
2. Recent examples of similar depositional environments are prevalent in the marine environment. However, in fresh water environments, sulfide deposition is not as prevalent because of the lack of nutrients, particularly sulfate and nitrate.

Application of these ideas to the closure of a sulfidic tailings facility leads to two conclusions:

1) If a sulfide deposit is to be closed, it best be left in a state where anoxic conditions can be maintained. This usually means a stagnant water situation.

2) If a system is to be maintained undisturbed in an anoxic state, the reactants to produce sulfides and carbonates need to be readily available.

Geomicrobiology principles help to explain how constituents in a water / sediment environment can react rapidly enough to consume dissolved oxygen. In addition, the proper microbially catalyzed reaction can add alkalinity to the aquatic system so that carbonates and hydroxides precipitate (Ehrlich, 1981). An important example of this process is the reaction upon which the sulfate-reducing microbial consortia survive (Postgate, 1979):

$$2\ H^+ + SO_4^= + 2\ \text{"}CH_2O\text{"} \dashrightarrow H_2S + 2\ H_2CO_3$$

Here, "CH_2O" represents organic matter such as cellulose and other carbohydrates, and the sulfate is dissolved in the water. Oxygen is not a reactant because the aquatic system is anaerobic. The oxygen needs to be consumed by microbially catalyzed organic decay (Ehrlich, 1981).

$$\text{"}CH_2O\text{"} + O_2 \dashrightarrow CO_2 + H_2O$$

Presence of the reactants is necessary to carry out these reactions. The sulfate is readily available in mine waters (Wildeman, Lapakko, and Kelsey, 1995). However, an adequate supply of organic material is necessary to insure that any water reaching the tailings or buried waste materials promotes the precipitation of sulfides and carbonates instead of the oxidation of pyrite. Shared use of the subject facility for tailing and sewage disposal is currently under consideration. Such use may well provide additional organic nutrients to insure anoxic conditions during operation and closure of the facility.

In geologic situations where a depositional environment is isolated from oxygen, water is typically the isolating agent (Maynard 1983, Stumm and Morgan, 1981). Such a situation has already been experienced with tailings on an unintentional or unregulated basis (Robertson, 1989). The Canadian Mine Environmental Neutral Drainage (MEND) program has been directing a study of four sites where tailings were disposed into freshwater lakes in Canada (Robertson, 1991). Preliminary results (MEND, 1992) have shown that anaerobic conditions have been maintained and release of heavy metals has been minimal. In fact, normal biologic activity has returned to some of the lakes in a relatively short time after tailing deposition. If subaqueous disposal appears to be functioning in unregulated situations, then geochemical-based design and construction of a facility to promote anaerobic subaqueous conditions should meet at least with equal success.

For closing and reclaiming the tailings facility, the above arguments lead to subaqueous storage of reactive materials along with development of processes to promote and naturally maintain an anaerobic environment. Applying the guidelines of maximizing the pros and minimizing the cons of subaqueous anaerobic storage leads to the decision that construction of a wetland environment in the reclamation cap is the best way to insure anaerobic conditions in the tailings while isolating the reactive materials (East and others, 1994). Design and construction of wetlands to promote sulfate reduction have been successfully used to treat acid rock drainage (Wildeman, Gusek, and Brodie, 1993). This method of sub-aqueous disposal, as opposed to burial in a lake, was an integral part of the reclamation cap design.

Upon reviewing the relevant geochemical and geotechnical principles and applying them to design and construction, the following guidelines were followed by East and coworkers (1994):

1) Because the tailings would originate from sulfidic ores, the closure objective was to minimize diagenetic reactions that might release contaminants, and maximize the geochemical stability of minerals that were formed under anoxic conditions.

2) The tailing facility would be located in an area where there is a net accumulation of moisture so that a water cover would be assured even in times of less that average precipitation.

3) The amount of exposed water should be minimized so that release of contaminants to the environment by that route would be small. Also, this would eliminate problems with overturn, evaporation losses, wind, waves, and hydraulic head associated with large areas and depths of free water. This would imply that the anaerobic environment would be created in the substrate of a wetland rather than in the sediment at the bottom of a lake.

4) Flow of air and water through the tailings would be restricted so that the amount of oxygen that could possibly enter the system is minimal.

5) Provisions would be made to capture any water flowing through the tailings. The flow through the buried tailings would be directed downward to ensure that any contaminants in the water flow away from the surface ecosystem.

6) A continuously submerged cover would be constructed in such a way that dissolved oxygen and other oxidizing agents in the water such as Fe(III) and nitrate would be completely consumed before the water reached the tailings.

7) To effect criteria 4 and 5, the cover soil would have a low hydraulic conductivity, but be slightly higher than the hydraulic conductivity of the tailings. To effect criterion 6, the cover would have sufficient organic material in the soil to insure continuous activity of anaerobic bacteria and have the means to turally replenish consumed organic nutrients with a robust plant cover.

8) Proper and timely groundwater management would minimize the head on the geomembrane liner. During operation, the groundwater level would be depressed, preventing the liner from "floating". At closure, the groundwater level would be allowed to rise reducing the differential head on the liner system and thus minimizing water migration through the tailings.

The Reclamation Cap

Because physical tests showed the tailings consolidate well enough to support light traffic, a complete reclamation design program is possible. To meet the guidelines given above, a six layer reclamation cover shown in Figure 2 was designed. From top down, the function of each layer is described.

1) A 0.6 m organic-rich soil layer to support vegetation. The vegetation will provide erosion control and supply organic nutrients to the lower layers to promote anaerobic activity.

2) A geofabric filter to prevent migration of fine material from the soil cover to the lower layers.

3) An upper caprock layer of coarse material to serve as a capillary break to water migrating from lower layers and to promote horizontal flow off the facility of oxygen-rich surface flow and precipitation.

4) A lower caprock layer of fine-grained rock to maintain stagnant water over the tailings even in drought conditions.

5) A filter fabric under the caprock to confine the lower organic layer, to serve as a construction base for the upper layers, and to confine the tailings.

6) An organic layer that serves as an oxygen consumer and generator of $S^{=}$ and HCO_3^-.

Because the tailings are a silty, consolidated material, the hydraulic conductivity is very low and little water will be expected to travel down through the facility. The bottom organic layer can be considered to be an insurance zone for the elimination of oxygen. Results from the MEND studies (Robertson, 1989, 1991, MEND, 1992) show that the stagnant conditions in the fine-grained caprock layer should generate anoxic conditions.

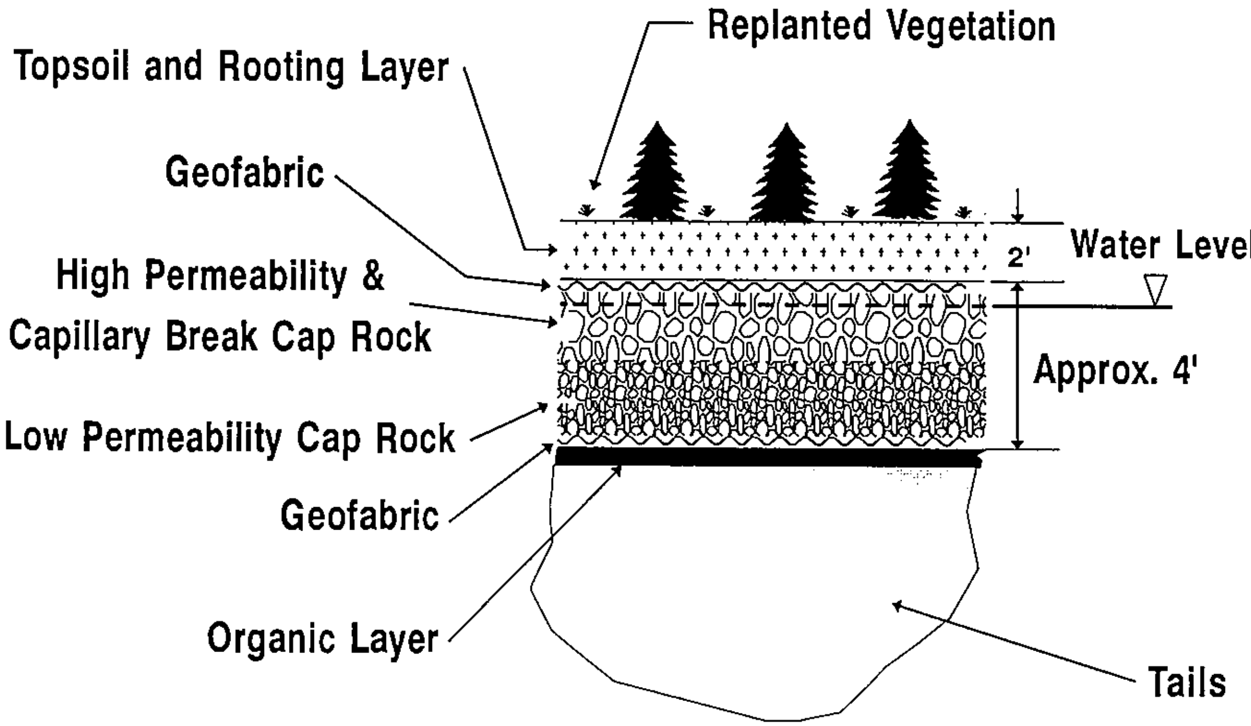

Figure 2. Schematic diagram of the multi-layer reclamation cover.

The water level shown in Figure 2 is designed to be in the high permeability caprock layer less than one meter below the surface. This will be the case over most of the surface of the reclamation cover. However, due to the natural grade of the tailings, the surface will be sloped so that exposed water will occur only down the centerline of the cover.

Conclusions

Closure of waste rock and tailings facilities requires design of a reclamation cover that can serve two purposes:

1) Isolate reactive materials from oxygen,
2) Chemically condition any water and air that reaches the material such that reactions that release contaminants are eliminated and reactions that stabilize reactive minerals are promoted.

Design and problem solving that combines control of water flow with generating the proper chemistry in the water that does flow through waste containment and earth structures could be termed geochemical engineering. Such principles were used to design a reclamation cover and liner system for a tailings facility where subaqueous confinement of reactive materials was the logical method for closure. To be most effective, both the bottom liner and the reclamation cap are multi-layer systems. Each layer serves a particular physical or chemical purpose so that flow control and chemical conditioning of the water are effectively achieved. A historic net surplus of available cover water insures the longterm feasibility of such a design.

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TESTS OF THE ABILITY OF HEAP LEACH MATERIAL TO SUPPORT PLANT GROWTH[1]

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Abstract: The ability of heap leach pads to support plant establishment is not documented in the scientific literature on mine reclamation. Two greenhouse studies were initiated to examine plant growth potential in this material. In the first study, *Zea mays* was used to compare growth in heap leach material before chemical treatment and in water rinsed post-treatment (after sodium cyanide, sodium hydroxide, cement, lime, and floculant addition) material. Soil mix amendment was essential for growth in post-treatment material and liquid fertilizers improved growth. The second study focused on the potential growth an survival of *Acacia greggii* (a species native to the mine site) in amended and unamended post-leach material with several liquid fertilizers. This species grew and survived in unamended material, but below-ground growth improved with the addition of non-ore bearing spoils (overburden) as an amendment.

Additional Key Words: Gold Mine Reclamation; Heap Leach; Overburden; *Zea mays*; *Acacia greggii*; Mojave Desert.

Introduction

Spoils from gold mining will remain as permanent features of the post-mining landscape. Mine spoils are often deficient in nutrients such as N, P, K, Ca, and Mg and have high concentrations of toxic materials (Pichtel et al. 1994). The process of extracting gold by leaching crushed ore bearing material with sodium cyanide, sodium hydroxide, cement, lime, and floculant (a high molecular weight polymer) alters chemical properties and texture of the crushed rock. The leach pad material, in this experiment, was field classified as a silty-sandy gravel (Udden-Wentworth size classification) with a gravel composition ranging from granule to pebble (Leeder 1991). This coarse texture may adversely affect nutrient and water retention. All of these conditions may inhibit plant establishment on mine soils. The ability of heap leach pads to support plant growth is not documented in the scientific literature on mine reclamation. However, amending other spoil types with soil and nutrients has improved vegetation establishment and decreased uptake of toxic materials in some mining operations (Apel 1983).

Two greenhouse pot studies were conducted at San Diego State University to determine the growth potential of plants in heap leach material. The first study compared plant growth in heap leach material before and after leaching. *Zea mays* L. cv Hopi blue (blue corn) was used as a test plant because it germinates readily and grows quickly. Plants were grown in thoroughly water rinsed pre-leach material (crushed ore less than 3/8 inch) and in post-leach material (leached ore: sodium cyanide, sodium hydroxide, cement, lime, and floculant), with and without a potting mix amendment and/or a liquid fertilizer. The second study examined growth potential of a native legume in post-treatment heap leach with amendments and rinses which may improve growth. *Acacia greggii* A. Gray (catclaw) was used because it is a potential species for revegetation of the heap leach pad. One recent experiment indicates that *A. greggii* has a high survival rate (87.9%) on non-toxic spoils (Fidelibus 1994). The current study examined seedling growth in treated and rinsed post-leach material with a 5 cm surface layer consisting of: 1) post-leach materials alone, 2) post-leach mixed with non-ore bearing spoils (overburden), and 3) post-leach mixed with growth media (pile of salvaged growth media). Fertilizer treatments of Triple Super phosphate, ammonium sulfate, and a Hoagland's solution were also examined. This was part of a larger study examining nitrogen and phosphorus uptake of plants grown in heap leach material.

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