CONFERENCE ON CYANIDE AND THE ENVIRONMENT
Tucson, Arizona • December 1984
Published by Geotechnical Engineering Program • Colorado State University • Fort Collins, Colorado 80523

IMPOUNDMENT DESIGN FOR CYANIDED TAILINGS - CASE HISTORY OF THE CANNON MINE PROJECT

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INTRODUCTION

One of the reagents used in the recovery of gold from ore is sodium cyanide. The toxicity of free cyanide is such that the disposal of tailings, which may contain cyanide, requires significant engineering effort to avoid possible loss of cyanide to the environment. The design of systems for the economic disposal and environmentally sound containment of the tailings from mines and mills, that employ cyanide in the metal recovery process, involves consideration of possible metallurgical processes, tailings treatment options, suitable disposal sites, and appropriate disposal methods. This paper discusses the options open to the metallurgist and the geotechnical engineer in planning an economic and well engineered disposal facility for tailings that may contain cyanide. The paper illustrates these issues by describing a case history of an impoundment, designed and currently under construction, at a mine where cyanide will be used in the recovery of gold from the ore.

GOLD ORE PROCESSING AT THE CANNON MINE

There are a number of unit processes to recover gold from ore. The process which is selected is usually based upon laboratory or pilot plant tests or both. Selection criteria include recovery, capital and operating costs, cyanide leaching amenability, etc.

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The flowsheet selected for processing Cannon Mine ore is shown in Figure 1. The ore is initially crushed underground with secondary crushing performed on the surface. Crushed ore is ground in a conventional rod mill-ball circuit using reclaim water. Cyclone overflow is sent to rougher flotation. Rougher tailings are thickened and then pumped to the flotation impoundment. Rougher concentrate is cleaned twice with cleaner tailings reporting to the head of rougher flotation. After thickening and filtering, the concentrate is leached with cyanide for eight hours. Pregnant solution is processed in a Merrill-Crowe unit to recover soluble gold and silver. Precipitate is melted in an induction furnace and the cooled slag is returned to the grinding circuit. Bullion is cooled into bars.

Primary cyanide leach tailings are sent to the autoclave plant for oxidation of the sulfides and some carbon. After neutralization with limestone and lime, the slurry is again leached with cyanide in a secondary leach section. After eight hours of agitated leach, the slurry is filtered with the pregnant solution being sent to the Merrill-Crowe plant. Secondary leach solids are sent to chlorine neutralization to destroy any residual free cyanide. This tailings slurry is sent to the flotation tailings sump. The combined flotation-leach tailings are sent to the tailings impoundment.

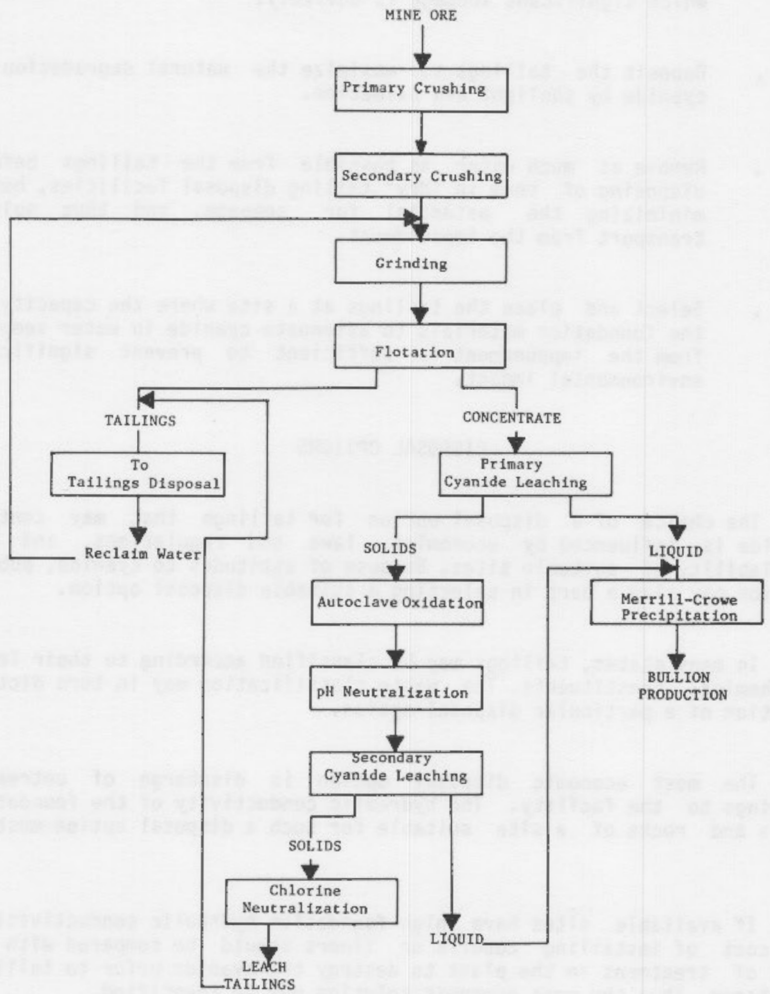
CYANIDED TAILINGS DESIGN OPTIONS

Prior to the adoption of strict pollution control laws, cyanide had been used in the recovery of gold and the tailings discharged, after little or no treatment, to impoundments. Natural processes on the surface of the impoundment, within the tailings, and in the foundation subsoils and rocks at the impoundment, were usually sufficient to preclude or reduce detrimental environmental impact. Increasing awareness of the potential for the impact of tailings on surface and ground water, has led to the passage of laws and regulations that impose a need for tailings disposal options with a lesser impact than those previously considered reasonable.

For these reasons different options for the proper disposal of tailings that may contain cyanide have been defined. Options considered in this paper include:

- Avoid the use of cyanide by adopting an alternative reagent or metallurgical process.

- Destroy the cyanide before the tailings leaves the plant (oxidation with either chlorine or ozone are two possible options).



ASMAERA MINERALS (U.S.) INC.
Cannon Mine
Flowsheet

Figure 1

- Deposit the tailings in a "tight" impoundment, i.e. one from which significant seepage is unlikely.

- Deposit the tailings to maximize the natural degradation of cyanide by sunlight and oxidation.

- Remove as much water as possible from the tailings before disposing of them in "dry" tailing disposal facilities, hence minimizing the potential for seepage, and thus solute transport from the impoundment.

- Select and place the tailings at a site where the capacity of the foundation materials to attenuate cyanide in water seeping from the impoundment is sufficient to prevent significant environmental impact.

DISPOSAL OPTIONS

The choice of a disposal option for tailings that may contain cyanide is influenced by economics, laws and regulations, and the availability of suitable sites. Because of attitudes to cyanide, public opinion may play a part in selecting a suitable disposal option.

In many states, tailings may be classified according to their level of chemical constituents. The waste classification may in turn dictate adoption of a particular disposal option.

The most economic disposal option is discharge of untreated tailings to the facility. The hydraulic conductivity of the foundation soils and rocks of a site suitable for such a disposal option must be low.

If available sites have high foundation hydraulic conductivities, the cost of installing cutoffs or liners should be compared with the cost of treatment in the plant to destroy the cyanide prior to tailings discharge. Thus the most economic solution may be identified.

If the cyanide is not destroyed in the mill, consideration must also be given to the transport of the tailings from the mill to the impoundment. If the mill is distant from the impoundment, and the pipeline traverses property where a tailings spill would be unacceptable, it may be necessary to consider relocating the mill to a site close to the impoundment.

Whatever solution is adopted to protect the environment from cyanide contamination, the designer must keep in mind the possibility that the ore or the actual process employed in the mill may involve the use of considerably more cyanide than initially envisaged. The tailings in the impoundment may, as described by Robertson et al (1984) contain very high levels of cyanide. Hence the water seeping from the impoundment may contain elevated levels of cyanide. To deal with such an eventuality, provision should be made in the design to collect and treat the seepage water for release, or to return the seepage water to the impoundment.

The designer of the cyanide tailings impoundment should also consider the following possible problem: seepage through an undetected or ungrouted joint may be more rapid than anticipated. Therefore less attenuation than anticipated may occur, and seepage water quality may be affected. Possible approaches to this problem are a carefully designed and installed grout curtain and an impoundment layout that makes it possible to collect and treat unacceptable seepage.

If the impoundment is to be constructed in a hot, dry climate, and the topography is relatively flat, the impoundment can be designed to rise slowly and have large flat pools. Exposure of supernatant to wind and sun breaks down the cyanide. As discussed by Smith et al (1984), this occurs in South African tailings impoundments and has been adopted at a number of mines in the USA. Such an approach to the control of cyanide is seldom feasible for impoundments in wet, cool climates or where the site is steep and narrow.

On the basis of the discussion above we may conclude that selection of a suitable site for an impoundment to contain tailings from a mill where cyanide is used in the recovery of gold involves detailed consideration of economic, legal, and engineering factors.

CASE HISTORY: CANNON MINE, WENATCHEE, WASHINGTON

The Cannon Mine is just southwest of Wenatchee, Washington, a town about 160 km east of Seattle. The tailings impoundment will contain between five and ten million tons of gold tailings deposited over ten to fifteen years. The site chosen after a detailed site selection study is up Dry Gulch to the west of the mine.

Dry Gulch is part of a valley and ridge system that rises from the flatter, alluvial terrace on which the mine and the town of Wenatchee are situated. The elevation of the Gulch rises from 300 m at the alluvial terrace, to about 480 m at the impoundment site, to about 1,500 m at the upper end of the catchment boundary. The climate of the area is relatively mild and dry. Winters are characterized by light precipitation and cool temperatures, while summers are hot and dry. The mean annual precipitation is 230 mm and the annual evaporation is 760 mm.

The rocks at the site, Tertiary sandstones and siltstones of the Wenatchee Formation, are generally massive and constitute a strong and competent foundation. Bedrock hydraulic conductivity decreases from 10-6 m/sec at the surface to less than 10-10 m/sec at about 50 m depth.

The gold occurs as a hydrothermal deposit in the siltstone of the Swauk Formation. The ore will be ground to ninety percent less than 200 mesh and the gold will be extracted by the process illustrated in Figure 1. As indicated, the cyanide leach slurry will be neutralized with chlorine, then mixed with the flotation tailings before discharge at the impoundment.

Table 1 gives the chemistry of the mixed tailings and the flotation tailings supernatant liquids. The bulk of the cyanide is chemically complexed (compare total cyanide at 284 mg/l with free cyanide at 0.35 mg/l), hence chemically unreactive and not harmful. The free cyanide level of 0.35 mg/l presents no problem at the neutral pH of the tailings solution, although it exceeds the U.S. Public Health Services limit of 0.2 mg/l.

The chemical composition of seepage from the tailings impoundment is not necessarily the same as the slurry liquid composition at the time of tailings deposition. It is subject to modification by a number of processes, the most important of which are: re-leaching of the tailings solids with rainwater and snowmelt and hydrochemical reduction in the tailings mass.

In order to assess the potential for modification of the tailings liquid chemistry that might occur in the pool on top of the impoundment, mixed tailings were equilibrated with simulated rainwater (distilled water with hydrochloric acid to pH 5). The resultant chemistry of the supernatant is given in Table 2. The table indicates an increase in the levels of free cyanide and iron, and shows that overall the leaching by rainfall and snowmelt will improve or not significantly alter the seepage liquid chemistry from the tailings impoundment.

To simulate hydrochemical reduction of interstitial tailings liquid, a sample of the mixed tailings was equilibrated with a 10-percent mass-to-volume sodium bisulphite (Na2S2O3) solution. Sodium bisulphite was selected as a chemically conservative reducing agent that

TABLE 1

CHEMISTRY OF "MIXED" TAILINGS AND FLOTATION TAILINGS LIQUIDS

Parameter	Mixed Tailings Supernatant	Floatation Tailings Supernatant
pH value (units)	7.17	7.30
Total dissolved solids	4320	440
Sulphate	1660	170
Chloride	1040	15.5
Total cyanide	284	<0.05
Free cyanide	0.35	<0.05
Sodium	480	90
Iron	10	<0.05
Arsenic	0.07	0.01
Cadmium	<0.01	<0.01
Cobalt	0.33	<0.01
Copper	0.03	<0.01
Lead	<0.01	<0.01
Mercury	0.0024	<0.0003
Nickel	<0.05	<0.05
Selenium	<0.01	<0.01
Silver	<0.01	<0.01

Note: All values in mg/l, except pH

TABLE 2

REACTION PRODUCTS CHEMISTRY OF "MIXED" TAILINGS

Parameter	Mixed Tailings Reduced with $Na_2S_2O_3$	Mixed Tailings Leached with Rainwater
pH value (units)	5.17	4.80
Total dissolved solids	N/A	2750
Sulphate	N/A	1587
Chloride	3750	202
Total cyanide	<0.05	57
Free cyanide	<0.05	2.58
Sodium	N/A	87
Iron	1100	18
Arsenic	<0.01	0.08
Cadmium	<0.01	<0.01
Cobalt	0.55	0.08
Copper	<0.01	<0.01
Lead	<0.01	<0.01
Mercury	0.0062	0.0011
Nickel	5.4	<0.05
Selenium	<0.01	<0.01
Silver	<0.01	<0.01

Note: All values in mg/l, except pH

would not interfere with the results. The chemical composition of the resultant equilibrium solution is given in Table 1. The important observation is that both the total and the free cyanide and copper are decreased to below analytical detection limits.

Seepage from the impoundment will occur in the upper fifty feet of the sandstones. Attenuation will occur in this zone. The yellow-brown rocks in the upper zone are oxidized and weathered. The lower rocks are relatively reduced and gray. The attenuation capacity of both zones was tested according to standard EPA procedures (1977). This involved agitation for 24 hours of the sample at a 16:1 liquid to solid ratio with the mixed tailings. Table 3 summarizes the partition coefficients describing the attenuation capacity of the two rock types. The results indicate significant attenuation of total cyanide, but no attenuation of free cyanide.

A one-dimensional solute transport model was used to predict the rate and extent of solute migration in the near-surface groundwater downstream from the impoundment. Seven cases were analyzed using the parameters given in Table 4 and for values of the partition coefficient varying from zero to ten. The chemistry of the seepage from the tailings was assumed to be the worst case that could possibly occur. The results of the simulations are given in Table 5. This table shows that, with no attenuation, dispersion causes a fifty-percent reduction in solute concentrations at the downstream toe of the embankment. For partition coefficient values above three, the downstream solute concentrations are radically reduced to less than 0.0001 percent of the original seepage concentrations. Sulphate, total cyanide, arsenic, cobalt, and copper are reduced to below detection limits before the downstream toe of the impoundment embankment. Non-attenuated free cyanide is reduced to fifty percent of the initial value.

The work described above shows that seepage from the tailings impoundment will have no apparent effect on the downstream groundwater quality, even near the impoundment itself. Attenuation of total cyanide and oxidation of the free cyanide in the impoundment, together with immobilization of the free cyanide in the tailings mass, are important reasons for this result.

Figure 2 is a cross section through the embankment. The zone 1 material is a clayey silt with a low hydraulic conductivity. This will inhibit seepage from the tailings. A grout curtain will be installed beneath the core. The grout curtain will prevent seepage through joints in the rock. The seepage and attenuation studies did not consider the presence of the curtain, which will further tend to reduce flow rates and the possibility of solute transport.

At the Cannon Mine, the decision to deal with cyanided tailings by treatment in the mill prior to discharge to the impoundment was based as

TABLE 3 PARTITION COEFFICIENT VALUES: "MIXED" TAILINGS ATTENUATION TESTS

Parameter	Oxidized		Reduced		Alluvium	Mean (Where Applicable)
	1	2	1	2		
Sulphate	3.95	4.24	4.05	3.57	3.43	4 (3.4 for alluvium)
Total dissolved solids	3.12	1.44	3.07	3.26	2.52	3.2 (2.5 for alluvium)
Total cyanide	8.2	6.66	14.1	11.5	6.3	Variable*
Sodium	3.66	3.66	3.96	3.96	2.97	3.8 (3 for alluvium)
Arsenic	11.4	13.7	13.7	13.7	9.14	>10
Cobalt	0.97	1.45	1.45	0.97	1.45	1.24
Copper	>10.7	>10.7	>10.7	>10.7	>10.7	>10

* 7.4 oxidized, 12.8 reduced, and 6.3 alluvium

Notes: 1) Cadmium, lead, nickel, selenium, and silver are not present.

2) Iron, free cyanide, and mercury show no attenuation.

TABLE 4 INPUT PARAMETERS FOR 1-D SOLUTE TRANSPORT MODEL: METRIC AND IMPERIAL EQUIVALENT UNITS

Parameters	Metric	Imperial
Flow		
Path length 1*	365 m	1200 ft
Path length 2*	548 m	1800 ft
Distance increment	27.5 m	90 ft
Time		
Total simulation	18,250 days	18,250 days
Time increment	1,825 days	1,825 days
Dispersivity		
Longitudinal	5 m	16.5 ft
Velocity	0.0078 m/day	0.0256 ft/day
Attenuation		
Bulk density	2.59 g/cm^3	162 lbs/ft^3
Porosity	0.4	0.4
Partition coefficient	Variable (D- 10)	Variable

Notes: 1* Distance to downstream toe of embankment

2* Distance to seepage control dam

TABLE 5 PREDICTED DOWNSTREAM CONCENTRATIONS BY THE SOLUTE TRANSPORT "MIXED" TAILINGS DISPOSAL

Parameter	Partition Coefficient (Kd)	Initial Concentration (Co)	Concentration (C_1) @ 365 m	Concentration (C_2) @ 548 m
Sulphate	4	1660	<0.2	<0.2
Total dissolved solids	3.2	4320	86	0.4
Total cyanide	>7	284	<0.03	<0.03
Free cyanide	--	0.35	0.18	0.105
Sodium	3.8	480	5	0.05
Iron	--	10	5.1	3
Arsenic	>10	0.07	<0.0001	<0.0001
Cobalt	1.24	0.33	< 0.008	<0.0001
Copper	>10	0.03	<0.0001	<0.0001
Mercury	--	0.0024	0.0012	0.0007

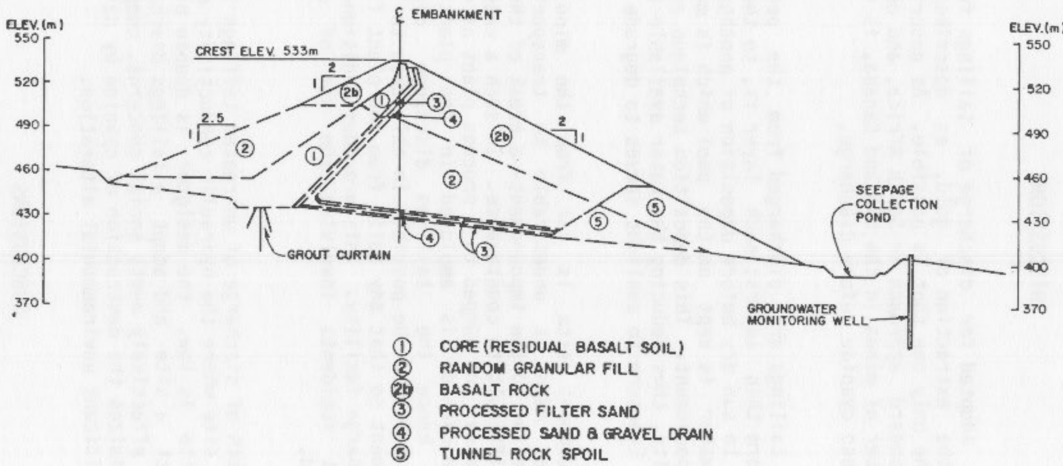


FIGURE 2. CANNON MINE TYPICAL EMBANKMENT CROSS SECTION

much on the proximity of the project to the town, as on the hydraulic conductivity of the impoundment foundation bedrock, and the desire to create a tailings pile with insignificant pollution potential.

DISCUSSION

The approach adopted for discharge of tailings from a mill that uses cyanide in the extraction of gold, as described in the case history, is not the only one that is possible. As described by Smith et al (1984) the standard approach in South Africa, and one that has been adopted at a number of mines in the USA and Canada, is not to treat the tailings to suppress cyanide before discharge.

Instead the tailings are discharged from the perimeter of the impoundment to form thin layers; each layer is, to the maximum extent possible, allowed to sun dry before deposition of another layer. Only a small amount of water is kept on the pool which is maintained in the center of the impoundment. This deposition technique effectively dries the tailings in situ, thus reducing the water available for seepage from the impoundment. Exposure to sunlight serves to degrade the cyanide.

If the impoundment site is far from the mine, environmental considerations may make it undesirable to transport the cyanided tailings in a pipeline to the impoundment--a break of the pipeline and a spill would be difficult to countenance. In such a case the ore may be slurried at the mine and pumped to a process plant at or closer to the impoundment. The cyanide is employed in the plant close to the impoundment and hence the tailings discharge directly to the impoundment. It may even be possible in this case to locate the plant above the impoundment so that any spill from the plant flows directly to the tailings discharge facility. This provides additional environmental protection against accidents involving the use of cyanide in the extraction of gold.

If the approach of discharge of untreated tailings in drying layers can be used at a site where the hydraulic conductivity of the soils and bedrock at the site is low, the designer is double blessed. In this case he can select a site and adopt a tailings discharge system that economically and effectively meets social concerns, complies with State requirements, maximizes the destruction of cyanide by natural processes, and prevents significant environmental alteration.

CONCLUSIONS

This paper has described design options for impoundments for the disposal of tailings that may contain cyanide. The case history illustrates the implementation of certain of the principles

On the basis of the case history and the options available, we conclude that economic, well engineered, and sound tailings impoundments may be designed and constructed to contain tailings from mills where cyanide is used in the recovery of gold. Such impoundments meet the requirements of the various new laws that regulate the disposal of such tailings, and hence the environment may be protected from significant or unacceptable impact.

REFERENCES

E.P.A., 1977, Methods of evaluations of solid waste materials.

Robertson, A. MacG., Hutchison, I. P. G., Ferguson, K. A., Ash, W., and Fisher, J. W., 1984, Cyanide control options: Lessons from case histories, Conference on Cyanide and the Environment, Tucson, Ariz., Dec. 12-14.

Smith, Adrian, Dehrmann, Alison, and Pullen, Rob, 1984, The effects of cyanide-bearing, gold tailings disposal on water quality in the Witwatersrand, Conference on Cyanide and the Environment, Tucson, Ariz., Dec. 12-14.