THE ECONOMIC AND ENVIRONMENTAL CASE FOR RECOVERING CYANIDE FROM GOLD PLANT TAILINGS

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ABSTRACT

The ability to recover cyanide from gold plant tailings has been known almost as long as the cyanidation process has been practiced, but there has been little incentive to process tailings in this way in the past. With the development of technologies that make it possible to recover and recycle free or complexed cyanide directly from gold plant slurry tailings, which indicates, on paper at least, significant cost savings compared to cyanide destruction, coupled with the introduction of legislation to seriously limit the discharge of cyanide to the environment in most gold-producing regions of the world, many companies are evaluating the cyanide recovery alternative.

There is arguably an even more compelling reason for mining companies to consider cyanide recycling. With the growing storm of negative public opinion that the use of cyanide in the mining industry is attracting – following several highly publicized spills over the last couple of years – the time has come for the gold industry to demonstrate environmental diligence and stewardship in the use of this commodity that is so vital for their industry. There is no doubt that the widespread implementation of cyanide recycling will reduce the impact of the cyanidation process on the environment, both by reducing the risk of spills (with less cyanide being transported from manufacturing plants to gold mines), and by reducing the loading of toxic and nontoxic metals and ions in the tailings.

This paper briefly discusses the pros and cons of the different processes that are available for the treatment of gold plant tailings to regenerate and recovery cyanide for recycling, and presents a technoeconomic argument for the incorporation of this technology into many gold plant flowsheets today.

INTRODUCTION

Interest in the recovery of cyanide from gold and silver plant tailings has heightened in recent years. This interest has been spurred by several factors:

- Increasingly stringent regulations throughout the gold producing world, governing discharge limits for free and total cyanide to tailings ponds and the environment.
- The increasing cost of active chemical treatment versus passive (natural degradation) treatment of tailing, to bring them in line with environmental regulations.
- The worldwide trend to processing of more complex gold ore bodies, which is usually accompanied by higher levels of cyanide consumptions and greater concentrations of cyanide (particularly the copper cyanide complex) in tailings.
- The growing negative perception of the general public for the gold mining industry, due to several highly publicized cyanide spills in recent years (breaches of tailings dams, accidents involving trucks carrying cyanide to gold plants, etc.).

The cost of recovering and recycling cyanide from tailings will generally be lower than the cost of purchasing new cyanide. When this cost benefit is added to the lower cost of tailings detoxification, a strong case can frequently be made for cyanide recovery.

In most cases, cyanide is recycled by converting it from the free or complexed form in which it exists in gold plants, to hydrocyanic gas, HCN. The negative perception of this highly toxic gas, and concerns about the ability of the mining industry to handle it safely in a processing plant, has probably been the single largest impediment to the implementation of cyanide recovery technology in the gold industry. In this regard, the mining industry can gain confidence and experience from the chemical industry, which manufactures sodium and calcium cyanide for the gold industry, and handles large quantities of HCN gas routinely and safely.

If the cyanide is present in the tailings as free cyanide (pKa = 9.4), it is possible to convert >99% of the cyanide to HCN gas by lowering the pH of the tailings to about 7.

$CN^- + H^+ <-> HCN$ (1)

If the cyanide is present as a metal cyanocomplex (Cu,Zn,Ni,Co etc), the pH must be reduced to more acidic values (which vary with the strength of the complex) to break down the complex and produce HCN gas. The addition of sulphide ions enhances this reaction by forming metal sulphide precipitates. The chemistry of cyanide recovery from metal cyanide complexes has been reviewed recently by Fleming (2001).

PRACTICAL CONSIDERATIONS

An important consideration when evaluating process options for the treatment of the gold or silver plant tailings for cyanide recovery, is whether to treat the tailings directly as a slurry, or to first separate the solids and liquids and treat only the liquid phase. In making this decision, the following factors must be taken into consideration:

- The cost of solid/liquid separation. If the solids and liquids have already been separated (in Merrill Crowe or heap leaching, for example) this is not a factor. If they have not been separated, the cost of solid/liquid separation must be included as part of the cost to recover cyanide, and this can be significant, particularly for high-clay, slimy or viscous slurries. In most cases, the washed solids will still have to be treated by a detoxification process to remove residual soluble cyanide species.
- Cyanide recovery by direct acidification of tailings, followed by volatilization and reneutralization of the HCN gas (known as the AVR process) is very much faster and more efficient from solution than from pulp, requiring lower volumes of air flow per unit volume of tailings treated and smaller equipment. Capital costs per unit volume of tailings feed are therefore lower for an AVR plant treating solution than for one treating pulp. In addition, attempts to implement the AVR process on tailings slurry have been dogged by severe scaling problems, such as encountered at DeLamar Mine in Idaho, USA and more recently at the Cerro Vanguardia plant in Argentina (Radcliffe, 2000).
- Operating costs are lower for cyanide recovery plants treating solution than those treating pulp. The main operating cost is the sulphuric acid consumed in lowering the pH to the desired final pH value. When treating solutions, this consumption is close to stoichiometric (i.e. half a mole of sulphuric acid per mole of cyanide). When treating pulp, the acid consumption can be 2 to 10 times higher, depending on the final pH required and the acid-consuming constituents in the ore.
- When the main source of cyanide consumption is the reaction to form copper cyanide complexes in solution (as is frequently the case), an added benefit of treating solution rather than pulp is the opportunity afforded to easily recover and sell the copper precipitate. The sale of these by-products can have a significant positive impact on cyanide recovery economics.

Despite the many positive attributes of treating solutions rather than pulps, the cost and efficiencies of solid/liquid separation will render cyanide recovery from solution unattractive in some cases. In these situations, resin in pulp processes offer the best solution and examples of this technology are discussed below.

In fact, ion exchange technology should always be considered, even when treating solutions for cyanide recovery, as the resin processes will usually upgrade the strength of the cyanide solution 20 to 100 fold prior to acidification/precipitation. This in turn will lower the overall capital cost and improve safety in the final cyanide regeneration steps of the process. In many cases, the cyanide strength in the eluate from an ion exchange process will be sufficiently high for direct recycling to leach, circumventing the need for volatilization of HCN (AVR).

The volatilization part of the AVR process is a relatively high capital cost component of the overall process. The decision on whether or not to preconcentrate by volatilization or ion exchange is based on the water-balance in the plant. If preconcentration is unnecessary, or is achieved by ion exchange, circumventing volatilization results in a simpler, safer and lower-cost plant.

Most of the process options for cyanide recovery have been tested at SGS Lakefield Research over the last few years, in the course of several laboratory and pilot plant investigations. Cyanide tailings solutions from several operating gold plants and new exploration properties have been tested, and the results of these investigations were published recently (Fleming, 2001). The discussion below is drawn from these experiences.

PROCESS ALTERNATIVES

DIRECT RECOVERY WITHOUT PRECONCENTRATION, BY TAILINGS RECYCLING

In order to ensure good leaching kinetics and high overall gold recovery, it is always necessary to add more cyanide during leaching than will be consumed in the leaching process. This excess cyanide reports to the tailings as uncomplexed or free cyanide, and it is often possible to recycle a portion of this cyanide at minimal cost. A number of gold plants around the world have adopted this approach.

The basic requirements to achieve this objective are firstly to recycle solution rather than slurry, and secondly, to satisfy an overall water balance in the plant. These requirements are met quite naturally in a heap leach operation, where the residual cyanide in the pregnant solution emerging from the bottom of a heap is recovered by simply recycling this solution (after gold and/or silver recovery) back to the top of the heap. It is not so simple in a milling operation, but some of the residual free cyanide can be recovered by thickening the mill slurry prior to leaching, and again thickening the leach plant tailings prior to discharge. For example, if the feed and discharge from cyanidation/gold recovery can be thickened to 60% solids, and the leach/gold recovery operation is conducted at 40% solids, the net result is that about half of the free cyanide in the tailings is recovered and recycled. This is depicted schematically in Figure 1.

Pros

- The process is very simple with relatively minor capital cost (two thickeners, larger leach and CIP tanks) and minimal operating costs.
- The process does not require conversion of free cyanide to HCN gas.

Cons

- It is difficult to recover more than ~50% of the free cyanide in the tailings. The remaining tailings must still be treated by a detoxification process prior to discharge to the environment.
- Without additional processing, the cyanide present in tailings as metal complexes is not recovered.

DIRECT RECOVERY BY THE SART PROCESS

The SART process was developed by SGS Lakefield Research and Teck Corporation (MacPhail et al., 1998), and is similar to the previous process, in that there is no pre-concentration of cyanide. SART should be applied in those situations where there is a significant concentration of copper (or zinc) as weak-acid-dissociable (WAD) cyanide complexes in the tailings (or recirculating heap leach liquor). Metals are precipitated from solution by addition of acid (typically to ~pH 4-5) and sulphide ions (Fleming, 2001). The precipitate is recovered by thickening and filtration, and the liquor is neutralized and recycled to leach. The concentration of free cyanide in the recycle solution is essentially the same as the combined concentrations of free and WAD cyanide in the feed to the SART process.

The solids density in the primary reactor will usually be very low (in the 0.05 to 0.5% range), and therefore it is beneficial to thicken the precipitate prior to filtration. This also affords the opportunity to pump a portion of the thickener underflow back to the primary reactor, where it can act as seed material for new precipitate formation. With appropriate recycling and flocculation, solids densities of 5-15% can be produced in the thickener underflow, which results in the volumetric flowrate to the pressure filter being reduced by a factor of 100 or more. A schematic flowsheet is shown in Figure 2.

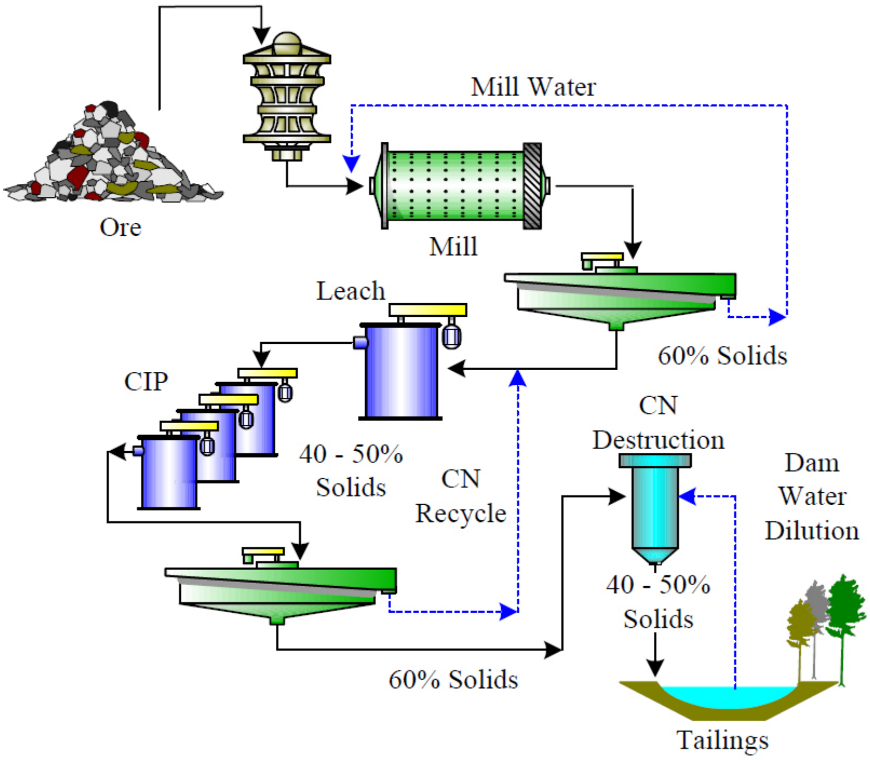

Figure 1. Simplified flowsheet for direct recovery of free cyanide from gold plant tailings

The basic chemistry of the SART process is identical to the MNR process, which was extensively tested in the 1980s (Potter et al., 1986). The fundamental difference between the two processes lies in the physical handling of the precipitate. In the MNR process, the Cu_2S precipitate is pumped directly as a low-density slurry from the primary reactor to a pressure filter. In the SART process, the volume of slurry reporting to the pressure filter is decreased by up to 99%, greatly reducing filter plant costs and improving the safety aspects of this potentially hazardous unit operation. Both the MNR and SART processes have been piloted, and a full scale SART plant has recently been built and commissioned at Newcrest's Telfer operation in Western Australia.

The experience gained during several laboratory programs and one pilot plant SART campaign can be summarized as follows:

- When the WAD cyanide complex in the tailings is copper (which was generally the case in these projects), the SART process produces a precipitate of almost pure Cu_2S, analyzing ~70% Cu and ~20% S. There was always minimal cyanide in the precipitate (<0.15%).
- Ferrocyanide and thiocyanate are not precipitated at all, and build up in the recirculating solution phase. They can be precipitated from a bleed stream by lowering the pH to about 2 (without sulphide addition).
- The copper precipitation reaction rate is fast (<5 minutes) and the precipitate flocculates readily (with appropriate flocculant addition) and settles rapidly, producing a fairly dense thickener underflow (~10% solids) and clear overflow.

The pros and cons of the SART process are essentially the same as the direct recycling approach, with the added advantage that revenue can be generated from the sale of high-grade copper (or zinc) sulphide precipitates.

DIRECT RECOVERY BY THE AVR PROCESS

The earliest experience in the mining industry with cyanide recovery from tailings was the AVR process, which was practiced at the Pachuca silver mine in Mexico and at the Flin Flon Mine in Manitoba, Canada (Davis, 1946; Flin Flon Mill Staff, 1946) more than 50 years ago. The process has been installed more recently at the Golden Cross Mine in

New Zealand, the DeLamar Mine in Idaho, USA, the Morro de Ouro Mine in Brazil and the Cerro Vanguardia Mine in Argentina, although only the two South American mines are currently operating.

The AVR process involves acidification of the gold plant tailings with sulphuric acid, to lower the pH from ~10 to less than 7, usually to pH 3 to 5. The process can be applied to solutions or pulps, although solution treatment is preferred in most cases for the reasons outlined above. During acidification, free cyanide and weakly complexed cyanide (complexes of Zn, Cd, Ni, Cu) are converted to HCN, which is then volatilized by passing a vigorous stream of air bubbles through the tailings pulp or solution. This operation is performed in a tall tower, which is baffled with plates or packed with inert media to improve gas/gas contact.

The air/HCN gas stream is scrubbed in a caustic solution in a second reactor tower to convert the HCN back to free cyanide ions for recycling. Scrubbing in a lime scrubber has been attempted, but has not been installed at any of the operating plants, mainly owing to concerns about scaling. It is possible to build up the cyanide concentration in the scrubber to the solubility limit of the sodium or calcium cyanide salt, although a practical limit of ~100 g/L CN is usually used. The process is described in detail by Riveros et al. (1993).

The experience gained from three laboratory/pilot campaigns conducted at SGS Lakefield Research, treating widely divergent feed materials, can be summarized as follows:

- The rate of conversion of free and complexed cyanide to HCN, as well as precipitation of metals, is rapid (<10 minutes), whereas the rate of stripping of HCN from the solution to the gas phase is slow (several hours for complete stripping). The HCN stripping rate can be significantly enhanced by heating the tailings, although this cost would be prohibitive in most cases.
- Given sufficient residence time in the HCN stripping reactor, the AVR process is capable of producing final effluents that are very low in cyanide and metals (CN_{TOT}, Cu, Fe <1 mg/L).

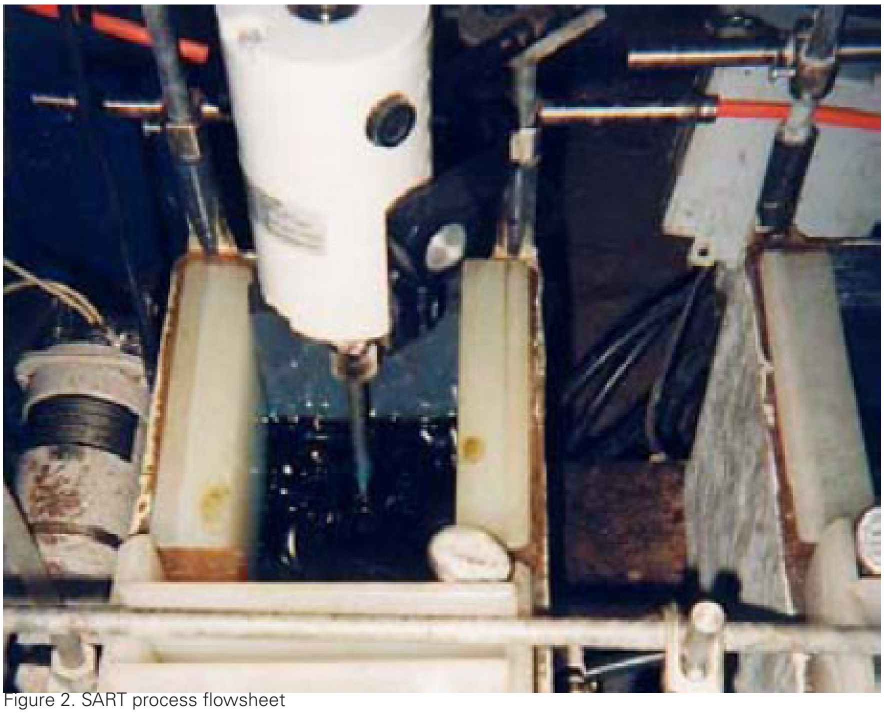

Figure 2. SART process flowsheet

- The pH of the acidification process must be reduced to <3 if the tailings contain significant amounts of copper cyanide complexes. It is not possible to recover any cyanide that is associated with ferrous or ferric cyano complexes.
- Acid consumption is close to stoichiometric based on total cyanide in solution, when treating solutions. In one campaign where solutions and pulps from the same operation were tested, acid consumption was 5 times higher for pulp treatment. The rate of HCN stripping from pulp was also significantly slower than from solution.

Pros

- The AVR process has been studied and practiced for many years and the practical and theoretical aspects are well understood.
- It is the only process involving HCN generation that has been applied successfully in the mining industry, with a wealth of experience gained from several operating plants around the world.
- In cases of high cyanide concentration in the tailings, the process has lowered the overall operating costs in those plants where it has been installed.

Cons

- Capital costs are higher than the alternatives, mainly due to the slow rate of HCN volatilization, and the resultant large size of the packed stripping tower.
- The process is not well suited to treatment of slurries because of (a) high acid consumption, (b) exceptionally slow HCN stripping rates and (c) the potential for severe scaling problems.
- In practice it is difficult to achieve low values of residual cyanide in the treated solution, and supplementary cyanide detoxification may be required.

INDIRECT RECOVERY WITH PRECONCENTRATION BY ION EXCHANGE RESINS

It is often inconvenient, costly or inefficient to recover cyanide directly from gold plant tailings. This is the case if the tailings pulp is difficult to separate into solid and liquid components (as occurs with laterite, high-clay, slimy or viscous ores) and also if the tailings solids are high acid-consumers. In these situations, direct acidification of the tailings results in high operating costs (due to high acid consumption) and inefficient cyanide and copper recovery (due to the loss of CuCN precipitate to the tailings). Air stripping of HCN from slurry is also inefficient, requiring long residence time in the stripping column and high air flowrates.

Anion exchange resins can play a very valuable role in these situations. The resin in pulp process is welldeveloped in the mining industry for other applications (uranium, gold recovery), and presents the opportunity to recover cyanide directly from pulp tailings, circumventing solid/liquid separation processes. Moreover, conventional commercial strong-base resins are well-suited to this application.

The most common cyanide species in gold plant tailings are free cyanide anions (usually 100 – 500 mg/L) and the cyano complexes of copper, zinc, iron and sometimes nickel.

The free cyanide anion has a very low affinity for anion-exchange resins, and can only be extracted efficiently after all the metal cyanide complexes plus most other anions (especially thiocyanate) have been extracted. However, free cyanide can be efficiently extracted if it is pre-complexed with a metal ion such as zinc (or copper) prior to ion exchange, as discussed below.

The ability of anion exchange resins to efficiently extract copper, zinc and nickel cyanide, as exemplified in the adsorption isotherms shown in Figure 3, presents an opportunity to recover these complexes when they are present in the tailings of a gold plant.

Nickel cyanide is uncommon in gold plant tailings, while cobalt (III) and iron cyanides form such stable complexes that it is impossible to break them down without simultaneously destroying the cyanide ion. Thus, these complex anions can be extracted from gold plant tailings by ion exchange, making the tailings amenable for direct discharge to the environment, but they do not yield their cyanide for recycling.

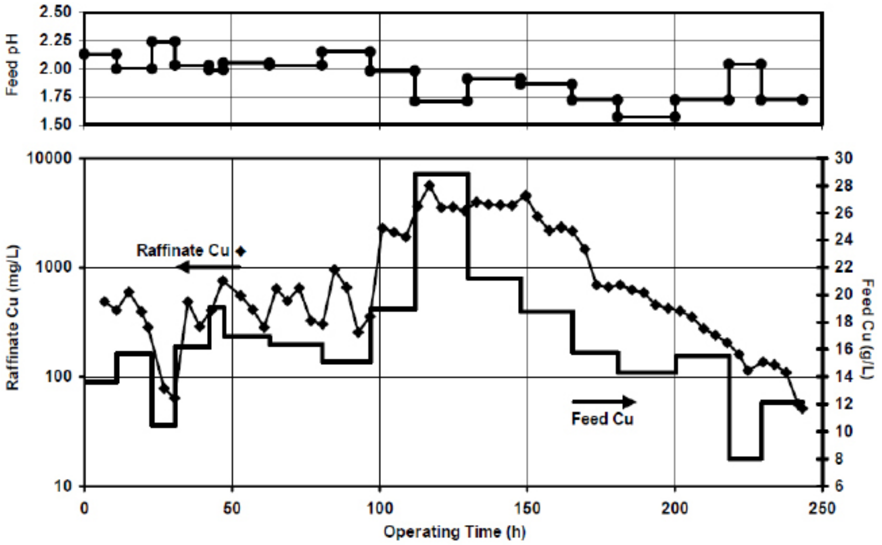

Figure 3. The equilibrium loading of various metal cyanide complexes from a plant leach liquor onto a strong base resin, A101Du (Fleming and Cromberge, 1984)

(a) Loading Enhancement by Zinc Complexation

Zinc cyanide is found naturally in many gold leach circuits, particularly those employing Merrill Crowe for final gold recovery. In addition, a zinc salt can be added to the leach tailings to pre-complex all of the free cyanide as the zinc cyanide WAD complex. Although this complex is the weakest of the WAD cyanide complexes ($Zn(CN)_4^{2-}$, log β_4 = 17.4), it has a very strong affinity for anion exchange resins, as shown in Figure 3.

Zinc cyanide loads onto a strong base anion exchange resin via the following stoichiometry:

$$(\circledR - N{+}R_3)_2\ SO_4^{2-} + Zn(CN)_4^{2-} \rightarrow (\circledR - N{+}R_3)_2Zn(CN)_4^{2-} + SO_4^{2-} \qquad (2)$$

where the symbol ® represents the resin matrix. The stoichiometry of equation 2 shows that each resin functional group effectively loads two cyanide ions, so not only does the pre-complexation reaction convert cyanide from the poorly loading free cyanide form to the strongly loading zinc cyanide complex form, it also doubles the total loading capacity of the resin for cyanide ions. Resins are capable of loading to their theoretical capacity (30-40 g/L zinc, 50-65 g/L cyanide) from quite dilute zinc cyanide solution (<100 mg/L Zn), and are able to produce very low levels of cyanide in the final effluent (<1 mg/L).

To elute the zinc cyanide, the loaded resin is treated with sulphuric acid, which breaks down the zinc cyanide complex completely, producing zinc sulphate and HCN gas in solution. If the acid solution (100-150 g/L H_2SO_4) and the resin are moved countercurrent to one another, it is possible to produce a strong HCN solution (>5% HCN) containing no excess acid (pH >5).

$$(\circledR - N + R_3)_2Zn(CN)_4^{2-} + {}_2H_2SO_4 \rightarrow (\circledR - N + R_3)_2SO_4^{2-} + ZnSO_4 + 4HCN \qquad (3)$$

It is necessary to separate the ZnSO4 and HCN in the strip liquor, so that the zinc can be recycled to the pre-complexation reaction. This is done by AVR. The HCN gas is volatilized from the regenerant solution in a stream of air, which is scrubbed in lime or caustic solution to recover the cyanide as the usable free cyanide ion. Because of the high concentration of HCN in the regenerant solution, the size of the stripping column will be relatively small compared to an AVR plant treating tailings solution directly.

$$2HCN + Ca(OH)_2 \rightarrow Ca(CN)_2 + H_2O \quad (4)$$

The barren regenerant solution can be recycled directly to the pre-complexation reactor, or it can be treated with lime or caustic to precipitate zinc hydroxide for sale, discard or recycling. A simplified flowsheet of this process is shown in Figure 4.

The only reagents theoretically consumed are sulphuric acid (stoichiometric consumption: 0.5 mole per mole cyanide recovered, or 1 kg H_2SO_4/kg NaCN) and lime (stoichiometric consumption: 0.5 mole per mole cyanide, or 0.75 kg $Ca(OH)_2$/kg NaCN).

A fairly basic operating cost comparison of recycling cyanide (from the free cyanide or zinc cyanide form) versus cyanide destruction is made in Table 1, from which it is apparent that recycling will be economically attractive in most cases. In addition, the various unit operations needed for a cyanide recovery plant (by ion exchange) require simple equipment, operated under ambient conditions. It is expected that the capital cost will be relatively low, with a payback time significantly less than the rest of the gold plant.

Pros

- The process can be applied to solutions or slurries, circumventing the need for solid/liquid separation in the case of milling operations.
- It is possible to recover all the free and WAD cyanide in the gold plant tailings without upsetting the water balance in the plant, and without the need for supplemental detoxification of the final tailings.
- The AVR process is applied to a small, highly concentrated solution of HCN, and it is therefore potentially safer than direct AVR on tailings, and will be more efficient and rapid.

Cons

- No commercial installations have been built yet.
- The process is more complex than direct recovery from tailings (without preconcentration of the cyanide).
- Handling of concentrated HCN in a small AVR plant is potentially hazardous, and this part of the plant must be carefully designed and engineered.

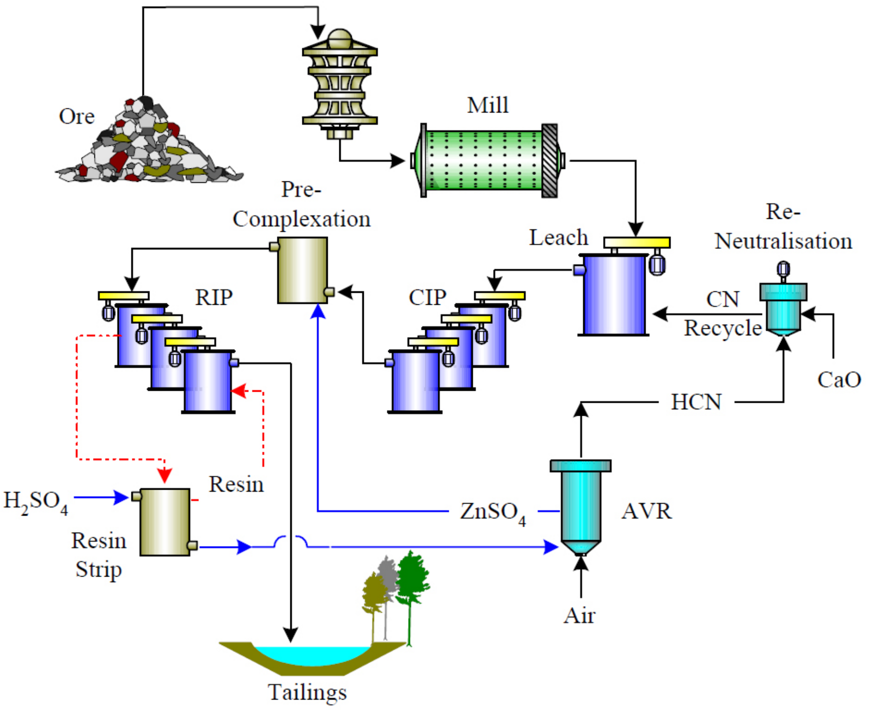

Figure 4. Simplified flowsheet for cyanide recovery from gold tailings slurry by ion exchange with zinc pre-complexation

Table 1. Operating cost comparison: Cyanide recycling versus cyanide destruction

	Cost of Recycled Cyanide (per kg NaCN) $ / kg
H_2SO_4 consumed at 1.2 kg H_2SO_4 per kg NaCN (20% excess assumed)	0.14 – 0.20
Lime consumed at 0.9 kg per kg NaCN (20% excess assumed)	0.14 – 0.20
Resin and zinc losses, labour, power and maintenance (range based on size of plant)	0.20 – 0.50
Total	$ 0.48 – 0.90
	Cost of New Cyanide (per kg NaCN)
Purchase Price of New Cyanide	1.20 – 1.50
Cost of cyanide destruction (quoted by Inco for SO_2 process)	0.65 – 2.40 ##
Total	$ 1.85 – 3.90

The wide range of costs for the Inco process takes into consideration variable CN- in the tailings (in the range 100 to 800 mg/L CN) and the variable cost of different SO_2 sources. Other CN destruction processes are generally more expensive than the Inco process.

The process should always be considered for the treatment of gold plant tailings in which the recovered cyanide is present in the form of free cyanide or the zinc cyanide complex. Non-recoverable forms of cyanide (ferrocyanide and thiocyanate, for example), do not load as well as zinc cyanide on the resin, and can be rejected to the tailings if desired. If the tailings contain significant amounts of WAD cyanide in the form of the copper cyanide complex, the zinc process is not ideal, and the Hannah process described below should be considered.

(b) Loading Enhancement by the Augment Process

The Augment process was developed by Lakefield Research and the DuPont

Corporation (Fleming et al., 1995) to recover copper and cyanide in gold plant tailings, by an ion-exchange resin based process.
The chemistry involved in the various unit operations of the Augment process was described recently by Fleming (2001).

The process was extensively tested at Lakefield Research in the 1990s, and it was demonstrated that copper cyanide and free cyanide could be extracted from gold plant tailings to low barren solution values (<10 ppm), in a continuous process that produced concentrated cyanide solution (~100 g/L NaCN equivalent) and ~99.9% copper cathodes as products. Consumption of acid and base were almost stoichiometric (~10% excess), as in the zinc cyanide (or free cyanide) case above. The economics of this process could, in most cases, produce slightly more favourable economics of cyanide recovery versus cyanide destruction (because of the additional revenue from copper sales) than those depicted in Table 1, for the zinc pre-complexation process.

The Augment marketing company has recently been dissolved, and the rights to this technology are held by the University of Reno in Nevada, USA.

Pros

- The same advantages as the process involving enhancement by zinc complexation, with the added benefit of revenues from the sale of cathode copper.

Cons

- No commercial installations have been built yet.
- The process is more complex than zinc cyanide enhancement. During piloting at Lakefield Research, it was shown that the cyanide to copper ratio is a key parameter that must be closely monitored and, in some cases, controlled, through all the unit operations of loading, elution, regeneration and electrowinning. The requirement for continuous, on-line analysis of copper and cyanide in solution creates analytical challenges, and it is anticipated that the efficient operation of an Augment process will require a highly skilled workforce.

(c) Loading Enhancement by the Hannah Process

The Hannah process (patents pending) was also developed at Lakefield Research, in collaboration with John A. Thorpe. Like the Augment process, it was developed with the treatment of copper cyanide-bearing gold plant tailings in mind, but is able to efficiently recover free cyanide and the cyanide associated with other WAD complexes as well.
The process is based on extraction with anion exchange resins, so can also be applied to solution or slurry tailings.

Whilst the details of the process cannot be published at this stage, since the application for patents is still under review, the following brief outline can be used to size major equipment and to calculate reagent consumptions:

- The process uses conventional, large-bead, strong base resins.
- The main purpose of the process is to recover cyanide, but it can also recover copper, zinc and thiocyanate (as a concentrated solution or as a CuSCN precipitate). If desired, thiocyanate can be rejected by the process, and report to the tailings.
- The optimum cyanide removal efficiency will vary with pulp composition, environmental regulations and local costs, but will normally be >90%.
- The preferred reagents for the process are: -

Consumption (mole/mole CN recovered)		
Reagent	Low CN:Cu(1)	High CN:Cu(2)
$Ca(OH)_2$	1.0	0.6
H_2SO_4	0.8	0.6
NaSH	0.2	<0.05
where (1) CN:Cu <5:1, and (2) CN:Cu >10:1.		

- Resin flow will be 0.6 to 1.2 litres of resin per mole of cyanide recovered (cyanide equivalent loading on resin = 22 to 44 g/L).
- Resin phase retention times in the loading tanks will be 1 to 2 hours. Two to four loading tanks in series will be normal.
- The volumetric ratio of tailings solution flow to countercurrent resin flow will vary with the composition of the tailings, but will typically range from 20:1 to 100:1.
- Total volumetric resin inventory in the plant (loading, elution and regeneration is expected to be in the range 0.5 to 2 times the volume of tailings solution processed per hour.
- Resin elution is done at ambient temperature, and the hold up time is about 1 hour.
- Resin regeneration is preferably done in columns, in a residence time of ~2 hours. The regenerant is alkalized to produce a concentrated $Ca(CN)_2$ solution for direct recycling to leach.

The Hannah process is expected to produce similar favourable economics as depicted in Table 1 above, and is currently being evaluated by two mining companies.

Pros

- The process enjoys the same advantages as the Augment process, with the added advantage of being simple to understand, optimize and operate.
- Unlike the zinc enhancement process, the Hannah process is able to treat tailings that contain both copper and zinc as WAD cyanide complexes, and produce separate ZnS and Cu_2S by-products.

Cons

- No commercial installations have been built yet.

ENVIRONMENTAL, SOCIAL, HEALTH AND SAFETY BENEFITS OF CYANIDE RECYCLING

The discussion above has centered on the technical aspects of cyanide recovery and the economic benefits that should flow from the implementation of this technology. As shown, the favourable economics alone should persuade gold mining companies to seriously examine cyanide recovery versus cyanide destruction in their mills.

There is, today, an even more compelling reason for gold mining company executives to seriously evaluate the option of recovering and recycling cyanide from gold plant tailings, and that is the positive impact that this technology will have on the environment and on the perception of the gold industry in the minds of the public, special interest groups, regulators and governments.

These less-tangible benefits of cyanide recovery can be summarized as follows: -

- The current 'best' practice is to oxidize cyanide in gold plant tailings to cyanate (and sometimes ammonia), and precipitate heavy metals (plus strongly bound cyanide) in the tailings, before release into a tailings dam or aquifer. Whilst this represents a significant improvement on the historical practice of releasing cyanide directly into tailings dams (and allowing air and sunlight to slowly decompose the cyanide), cyanide detoxification cannot be considered a 'clean' technology. For example, salts such as sodium cyanate and thiocyanate accumulate in aqueous solutions (and ultimately in the ground water) while heavy metals remain in the tailings. Whilst those species are less toxic than cyanide, cyanate represents a biological oxygen demand and nitrogen loading in aquifers, while ammonia is extremely toxic to aquatic life.
- Cyanide recycling reduces the need for new cyanide purchases, which in turn reduces the risk of cyanide spills in transit to a mine site. In addition, the preferred reagent for transportation is solid sodium cyanide, which must be carefully handled during manufacture, shipping and unloading at the mine site, to avoid exposure of workers to toxic dust.
- Cyanide recovery technology will extend the life of mines by allowing mining companies to process lower grade ores as well as ores that contain high cyanide-consuming minerals, such as copper sulphides and oxides. In several of the cyanide recovery processes, copper is recovered and can generate extra revenue for the operator, instead of becoming the death knell of a mine, as is often the case today.

CONCLUSIONS

Free and weak-acid dissociable cyanide are readily recoverable from gold and silver plant tailings solutions or pulps.

There are several processes available, and the choice of the best technology will be based on factors such as:

- The composition of the tailings.
- The form of the tailings (solution or pulp).
- The efficiency and cost of solid/liquid separation.
- The local environmental regulations for final discharge of tailings and bleed streams.
- The availability of local expertise and infrastructure.

In most cases, the cost of recycled cyanide will be less than one third the cost of new cyanide purchases, and capital investment to recover cyanide will pay back in less than 2 years.

The implementation of this technology will reduce shipments of new cyanide to mine metallurgical sites, reduce soluble salt loadings in tailings, and demonstrate proactive environmental stewardship to a public that has become increasingly hostile in recent years.

Cyanide recycle should be evaluated during project feasibility for all new gold operations, and should also be considered for retrofitting into many existing plants.

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