

A case study of CIP tails slurry treatment: comparison of cyanide recovery to cyanide destruction

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ABSTRACT

In this paper two cyanide recovery/destruction technologies, namely the Cyanisorb process and the INCO SO₂/Air process, are evaluated for the treatment of waste cyanide effluents from a gold mill of 12,000 tonnes of ore per day capacity. The comparison is made for CIP tails slurry of variable concentrations of free and weakly-complexed cyanide. Both direct treatment of the slurry prior to its discharge to the tailings pond, and treatment of the tailings pond discharge water are considered. After a brief description of the two technologies, order-of-magnitude capital and operating cost estimates are presented for several treatment options. It is concluded that: (i) the treatment of the tailings pond discharge water (by cyanide destruction) is the most economical of all options; (ii) the capital cost of cyanide recovery is relatively high, thus for this technology to be economically competitive, the level of recoverable cyanide in the CIP tails must be high (at least 200ppm); (iii) cyanide recovery alone cannot meet the environmental standards of less than 1ppm CN_T. Secondary treatment of the effluent by one of the cyanide destruction technologies most likely will be required following cyanide recovery; and finally (iv) concerns over cyanide use and management in certain parts of the world are expected to render cyanide recovery increasingly more attractive. © 2004 SDU. All rights reserved.

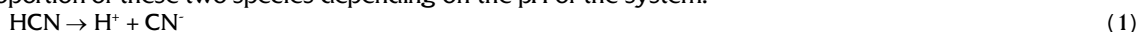
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1. INTRODUCTION

Cyanidation is the universally practised method of gold extraction from ore for over 100 years (Marsden and House, 1992). Cyanidation basically involves the dissolution of gold in an alkaline cyanide solution and the subsequent treatment of the leach slurry (using a Carbon-In-Pulp (CIP) circuit) or the clear leach solution (using the Merrill-Crowe Zinc Dust precipitation process or carbon adsorption columns) to recover and concentrate gold. The generated waste CIP slurry contains practically all the mass of the gold-depleted ore solids and the spent cyanide liquor.

Due to the toxic nature of cyanide, the CIP tails have to be contained and if necessary treated prior to the release of any effluent solution to the environment. A simplified CIP process flowsheet is shown in Figure 1. On the flowsheet, the treatment of CIP tails by either cyanide recovery or cyanide destruction technologies – the subject matter of this paper – is indicated as well.

The toxicity of the effluent and the effectiveness of the chosen detoxification or recovery technology depend on the chemical nature of the cyanide species contained in the spent solution. Cyanide is present in gold mill effluents as both free cyanide and in the form of metal cyanide complexes (Smith and Mudder, 1991). Free cyanide can exist as cyanide ion (CN⁻) and/or molecular hydrocyanic acid (HCN) – the relative proportion of these two species depending on the pH of the system:



The metal cyanide complexes can be distinguished into two groups: (i) the weak to moderately strong complexes – these complexes upon acidification or destruction of free cyanide (CN⁻) undergo dissociation (Reaction 2) releasing their cyanide content in the form of free cyanide; and (ii) the strong complexes, such as those of iron, that they are so stable as to effectively release no cyanide.

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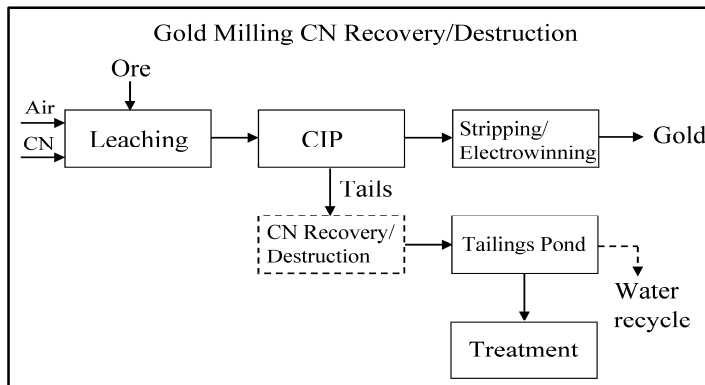


Figure 1. Generalized cyanidation – CIP-EW flowsheet incorporating CIP tails treatment



Environmental regulations usually specify effluent discharge criteria for both Weak Acid Dissociable (including free) cyanide (CN_{WAD}) and Total cyanide (CN_T) – the latter includes the strong (non-dissociable)-cyano complexes. In Canada, these standards are set at 0.1ppm CN_{WAD} and 1ppm CN_T , respectively. (Copper is also closely monitored in Canadian gold milling operations with its upper limit set at 0.3ppm). For the needs of the present study a single criterion is adopted, that of $CN_T = 1 \text{ mg/l (ppm)}$.

Until fairly recently (late 1970's) natural degradation of cyanide in tailings ponds was basically the only process employed for gold mill effluent detoxification (Smith and Mudder, 1991). To ensure consistent removal/destruction of cyanide, the industry over the last two decades has moved to either replace or simply supplement natural degradation with chemical treatment technologies. Among the latter methods, the INCO SO_2 /Air process has proven the technology of choice when it comes to the direct treatment of waste slurries (CIP tails). Degussa's copper-catalyzed H_2O_2 process, which is also widely used in industry, is best suited for the treatment of clear solutions and tailings pond waters as it results in high reagent loss when slurries are treated (Fleming, 2002). Caro's acid (produced by reaction of H_2O_2 with H_2SO_4) seems not to suffer from high reagent loss as does H_2O_2 when used for the treatment of slurries, and as such has been used in certain slurry treatment cases as is the case, for example, of Barrick's Goldstrike operation in Nevada, USA (Goode *et al.*, 2001). In the last ten years or so, however, there has been an increased interest in applying recovery, as opposed to destruction, technologies for cyanide (Fleming, 2001). One such significant commercial development is the Cyanisorb process (Stevenson *et al.*, 1994).

In this paper, a comparison between the INCO SO_2 /Air cyanide destruction process and the Cyanisorb cyanide recovery process for the case of a 12,000 tonnes of ore per day mill capacity generating CIP tails containing variable amount of CN_{WAD} is made. Order-of-magnitude estimates of capital and operating costs are made for various treatment options, and comments on the environmental advantages/disadvantages of each option are offered.

2. PROCESS DESCRIPTION

2.1. The INCO SO_2 /Air process

The SO_2 /Air process oxidizes both free cyanide and cyanide weakly-complexed with metals to cyanate (OCN^-) (Reaction 3). The cyanide strongly-complexed with iron is not oxidized but is removed as an insoluble copper ferrocyanide salt. The oxidizing agent is a combination of SO_2 plus O_2 (air) in the presence of a soluble copper (10–20ppm) catalyst:



Typically 3–5kg SO_2 /kg CN_{WAD} is required with the lower number corresponding to solution treatment and the higher number to slurries (Devuyst and Conard, 1993; Robbins, 1996; Goode *et al.*, 2001).

The best pH range for cyanide destruction is 8–9.5 (Devuyst and Conard, 1993). Since the cyanide destruction reaction generates acid, slaked lime needs to be added to control pH. Typically the consumption of lime is in the order of 2–4kg/kg CN for slurry treatment. Copper consumption is in the order of 0.2kg $CuSO_4 \cdot 2H_2O$ /kg CN.

A simplified flowsheet of the INCO SO_2 /Air process (Robbins, 1996) as it has evolved in the recent years is given in Figure 2. INCO's design criteria call for a single staged agitated reactor, wherein control conditions can be uniform. Supply of reagents is introduced and controlled automatically. The process control strategy is based on monitoring feed loading of cyanide (with or without simultaneously monitoring

of effluent cyanide concentrations) as well as process parameters (such as pH, CN_T and dissolved oxygen) and adjusting the SO_2 flow accordingly (Robins, 1996; Goode *et al.* 2001). Sulphur dioxide is most frequently added to the reactor as liquid SO_2 . Alternatively, elemental sulphur can be used to produce on-site SO_2 by burning - this is the cheapest SO_2 source; however, its environmental attractiveness is questionable. Finally, SO_2 may be supplied in other forms such as metabisulphite (or bisulphite salts). The INCO SO_2 /Air process has been successfully applied to both solution and slurry treatment in industry with over 60 plants practising it (Robins, 1996; Goode *et al.*, 2001).

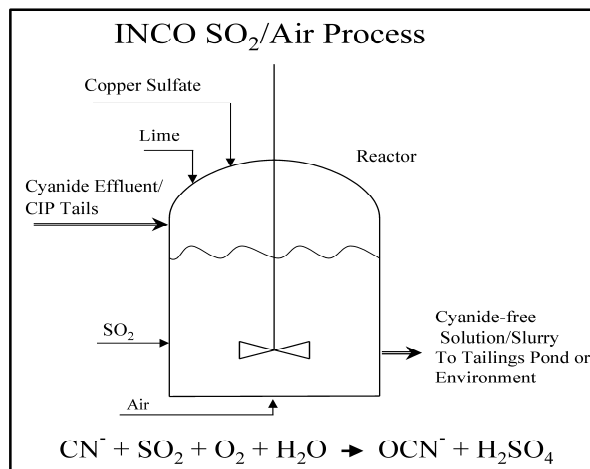


Figure 2. Simplified flowsheet of the INCO SO_2 /Air Process (adapted from Devuyt and Conrad, 1993)

2.2. The Cyanisorb process

Typically treatment of gold mill effluents (slurry or clear solution) by the Cyanisorb technology permits the recovery of about 70 to 95% of the free and weakly-complexed cyanide (Anonymous, 1995a; Stevenson *et al.*, 1994; Rule *et al.*, 2000; Botz and Mudder, 2002). The recovered cyanide is returned to the gold mill effectively, thus reducing the need for purchase and transportation of fresh cyanide reagent for use in the mill - highly important in today's social and political climate (Young *et al.*, 2001). In this respect, therefore, substantial economic and environmental benefits may be realized by the operating company. On the other hand, the treated effluent (still containing 10 to 20% of its initial cyanide content) cannot be discharged as is to the environment but has to be further detoxified. This can be done before it is discharged to the tailings pond by using, for example, one of the destruction processes like the INCO SO_2 /Air process or the Caro's Acid process. Or, the CIP tails may be discharged to the tailings pond with reliance on natural degradation to destroy the bulk of cyanide - a practice that may not be acceptable in regions where wildlife fatalities or other environmental concerns exist - and treat the pond water with one of the CN destruction processes such as the INCO SO_2 /Air process, Degussa's copper-catalyzed H_2O_2 process, or biological degradation. As such, therefore, the Cyanisorb process is not necessarily the complete solution to the problem of cyanide removal/destruction but it may have to be used in combination with one of the destruction processes (including the Natural Degradation Process) (Barbetti, 1999). Thus at the Golden Cross Mine (Scott, 1993) and Cerro Vanguardia Mill (Rule *et al.*, 2000), where cyanide recovery is practised, hydrogen peroxide is used for final effluent treatment. Given that application of the Cyanisorb process permits substantial savings on one hand in terms of cyanide recovery and re-use, and on the other hand substantial reduction in the cyanide loadings discharged into the tailings pond water system, and consequently lesser potential for contamination of the environment, the Cyanisorb process attracts a lot of attention.

The Cyanisorb process has evolved from the original AVR (Acidification, Volatilization and Re-neutralization) process concept (Ritcey and McNamara, 1978; Riveros *et al.*, 1993). The basic difference between Cyanisorb and AVR is the fact that Cyanisorb involves mild acidification (5.5-7.5) (although stronger acidification may be applied as done in the case of the Cerro Vanguardia Mill (Rule *et al.*, 2000)) as opposed to drastic acidification (down to pH 2 or lower) practiced in AVR; as well as the use of highly efficient packed bed towers by Cyanisorb to recover the HCN gas.

The Cyanisorb process flowsheet (Figure 3) (Anonymous, 1995b) consists of four stages:

- 1) Conversion of free cyanide and part of WAD cyanide to HCN with addition of H_2SO_4 . Effluent target pH depends on the particular cyanide solution composition. The higher the presence of relatively strong metal cyanide complexes like $Zn(CN)_4^{2-}$ and $Cu(CN)_3^{2-}$ the lower the pH of conversion is.

- 2) Stripping of HCN from the acidified slurry. Slurry from the conversion section is pumped to the stripping tower where HCN is removed from the solution into air which circulates in a counter-current fashion to the slurry.
- 3) Recovery of HCN gas into a basic (e.g. NaOH) solution (of pH ~ 12) via counter-current contact of the air stream from the stripping tower with the solution inside a packed bed recovery tower.
- 4) Neutralization of the HCN-stripped slurry/solution to pH 9 in a conventional circuit with lime before it is discharged to the tailings pond. The liberated free metal cations and the ferrocyanide complexes are precipitated out of solution during neutralization.

In practice, two independently operated stripping/recovery trains are used to provide flexibility and stability of operation. The conversion tanks, neutralization tanks, stripping and recovery towers are operated as a closed circuit with a negative pressure to prevent escape of HCN gas.

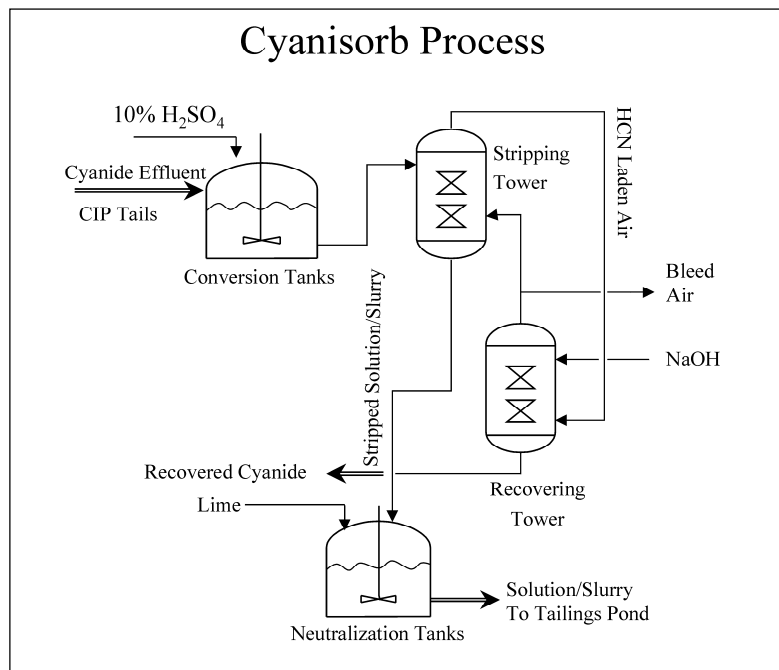


Figure 3. Simplified flowsheet of the Cyanisorb Process (adapted from Stevenson *et al.*, 1994)

It was reported in 2001 (Young, 2001) that the Cyanisorb technology has been implemented to at least 4 sites. The first operation was at the Golden Cross Mine in New Zealand in the late 1991 while another was applied to the DeLamar Silver Mine in Idaho, USA. The more recent applications known are those of Rio Paracatu, Brazil and Cerro Vanguardia, Argentina (Botz and Mudder, 2002). The Golden Cross application is the only one that has run with pulp (CIP tails) without apparent problems. The DeLamar plant (Botz and Mudder, 2002) and Cerro Vanguardia plant (Rule and Vago, 2000) started to operate with slurry but they run into problems due to either calcium sulphate or calcium carbonate formation and deposition on equipment. This necessitated conversion of the plants to solution treatment following thickening/CCD (Counter-Current Decantation) separation of solids. It is worthy to note that the Golden Cross plant operates at relatively elevated pH (around 7.5) while the ones that developed problems operated at lower pH (5 or lower) due to the higher metal (in particular zinc) content.

3. PROCESS COMPARISON

Capital costs depend on the size of operation; on the other hand operating costs depend on cyanide content in the effluent streams. In general in comparison to the destruction processes (e.g. the INCO SO₂/Air process) the Cyanisorb process has a higher capital cost but lower operating cost when the credit of the recovered cyanide is taken into account. But as mentioned earlier the Cyanisorb process is not a stand-alone technology from the standpoint of meeting environmental standards of effluent quality discharge. This is particularly so for milling operations with positive water balances at their tailings ponds i.e. tailings ponds necessitating discharge of surplus water to the environment.

The capital cost is considerably higher with the Cyanisorb process because of the cost involved with the construction of the stripping and recovery towers and with the electrical equipment and instrumentation.

In the rest of this report a number of options for cyanide control (recovery and/or destruction) for an anonymous gold mining operation are considered. Comparison of the various treatment options is made on the following basis Table 1.

Table 1
 Standard operating data used in this study

		units
Flow of gold mill tails	12,000	MTPD
CIP solids	45	wt%
CIP solution flow rate	611	m ³ /h
CN _{WAD} in effluent	100–400	mg/l
CN _{WAD} in tailings pond water	15	mg/l
Tailings pond water discharge flowrate	350	m ³ /h
Target discharge CN to the environment	<1 CN _T	mg/l

The ore grade is 2g Au/tonne while the annual gold production at the plant is taken to be equal to 250,000 oz per year. The prices/costs reported here reflects US\$ in the year of 2000 (Botz *et al.*, 2000; Botz and Mudder, 2002). Moreover, 90% plant availability is assumed.

3.1. Treatment of CIP slurry with the INCO SO₂/Air process - Option 1

In this option we consider treatment of the gold mill tails slurry by the INCO SO₂/Air process to completely destroy cyanide, i.e. bring the total cyanide content to less than 1mg/l. The process scheme is shown in Figure 4.

The cost of capital installed for a cyanide destruction facility using the INCO SO₂/Air process varies considerably from one installation to the other from US\$0.5 (€0.39) million for a 10,000 tonnes tails per day capacity (i.e. Barrick's Goldstrike Roaster operation (Goode *et al.*, 2001) to US\$1 to 1.5 (€0.78 to 1.17) million for a 5,000 tonnes tails per day capacity (Devuyt, 2004)). Taking as base case US\$1 (€0.78) million per 5,000 tonnes per day capacity and using the "six-tenths rule" (Perry and Chilton, 1973) the capital cost for the 12,000 MTPD facility is estimated at US\$1.7 (€1.33) million (see Figure 4 for sample calculation).

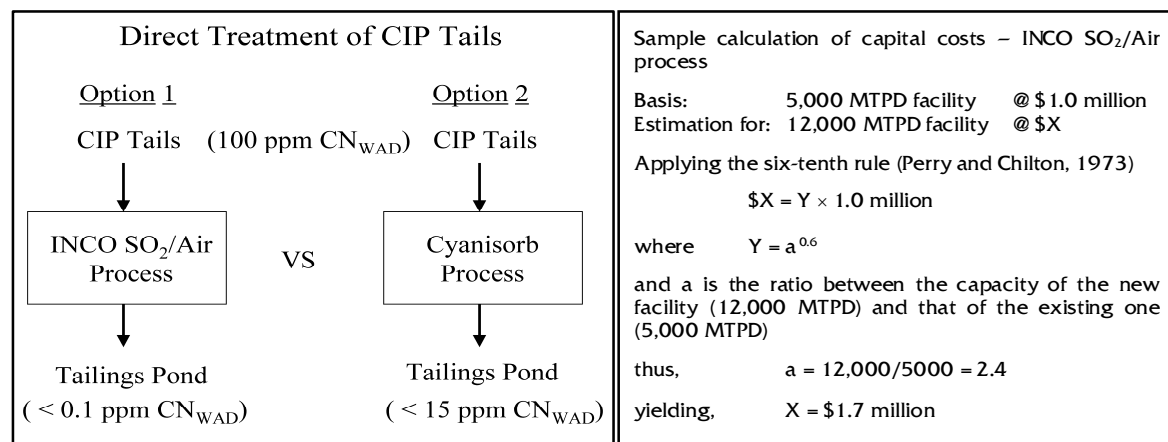


Figure 4. Schematic of direct treatment of CIP tails with the INCO SO₂/Air process or the Cyanisorb process (Options 1 and 2) and sample calculation of capital costs for the INCO SO₂/Air process

To calculate the operating costs the reagent consumption figures and costs listed in Table 2 were assumed. Power costs were scaled according to the "six-tenths rule". Labour, maintenance costs and royalty payments are excluded from this analysis.

For this scenario (100ppm CN_{WAD}), the annual operating cost was calculated (for details refer to Table 3) to be US\$1.1 million/yr (€0.86 million/yr) or US\$4.4/oz (€3.43/oz) Au recovered. In terms of cost per kg CN_{WAD} destroyed this corresponds to US\$2.4 (€1.87). This compares to US\$2.4/kg (€1.87/kg) CN_{WAD} reported by Barrick Gold for its 2000–2001 operation of its INCO SO₂/Air cyanide destruction plant Goldstrike, Nevada (Goode *et al.*, 2001).

Table 2
Reagent consumption and cost data (in US\$) – INCO SO₂/Air process

Reagent	Consumption	Cost(\$/kg CN)
SO ₂	5kg/kg CN destroyed	0.25
CaO	4kg/kg CN destroyed	0.1
CuSO ₄ ·5H ₂ O	0.2kg/kg CN destroyed	1.4
Power	490 kW*	\$0.052/kWh

* for CIP flowrate = 61 1m³/h (refer to Table 1)

Table 3
Estimation of operating costs (in US\$) – INCO SO₂/Air process – Option 1 (100ppm CN_{WAD}; 61 1m³/h or 60.5kg CN destroyed per hour)

Cost item	Usage	Unit cost (\$/kg)	\$/kg CN destroyed	\$/oz Au produced	\$/yr (million)
SO ₂	5kg/kg CN	0.25	1.3	2.4	0.59
CaO	4kg/kg CN	0.1	0.40	0.75	0.19
CuSO ₄ ·5H ₂ O	0.2kg/kg CN	1.4	0.28	0.53	0.13
Power	490 kW*	\$ 0.052/kWh	0.42	0.79	0.20
Total			2.4	4.4	1.1

* for CIP flowrate = 61 1m³/h (refer to Table 1)

3.2. Treatment of CIP slurry with the Cyanisorb process - Option 2

In this option we consider the treatment of the gold mill tails slurry by the Cyanisorb process with the purpose to recover 85% of the WAD cyanide content for recycling to the mill. The processing scheme considered is shown in Figure 4. It is apparent that this scheme does not meet per say the criterion of <1.0 mg/l CN_T but relies instead on natural degradation to lower further the cyanide content of the Tailings Pond waters.

According to earlier estimates (Stevenson *et al.*, 1994), the capital cost for a 12,000 MTPD capacity is (1994\$) US\$10 (€7.8) million. Similar estimates were reported more recently by Botz and Mudder, (2002); i.e. US\$4.5 (€3.51) million for a 3,000 MTPD mill throughput (which according to the “six tenths rule” corresponds to US\$10.2 (€7.96) millions for 12,000 MTPD capacity). For the purposes of this study a somewhat lower capital cost was assumed (US\$8.5 (€6.63) million for a 12,000 MTPD capacity) to reflect improvements brought to design and installation of these plants based on the accumulated experience.

To calculate the operating costs the reagent consumption and cost data listed in Table 4 were used. These are based on earlier figures reported by Stevenson *et al.*, (1994) revised appropriately in the light of more recent operating experiences (Botz and Mudder, 2002; Rule *et al.*, 2000). Once more, labour, maintenance costs and royalty payments were excluded. For this option the annual operating cost was calculated to be US\$0.95 (€0.74) million or US\$3.8/oz (€2.96/oz) Au recovered or US\$2.2/kg (€1.72/kg) CN recovered (for details refer to Table 5). These figures are lower than those calculated for Option 1 but not as favourable as one would have expected.

Table 4
Reagent consumption and cost data (in US\$) – Cyanisorb process

Reagent	Credit/Consumption	Cost (\$/kg)
NaCN	1.9kg/kg CN recovered	1.3
NaOH (50%)	3.1kg/kg CN recovered	0.3
H ₂ SO ₄ (98%)	1.5kg/m ³ solution or 1.8kg/tonne solids	0.10
CaO	1kg/m ³ solution or 1.2kg/tonne solids	0.10
Power	1060kW*	\$0.052/kWh

* for CIP flowrate = 61 1m³/h (refer to Table 1)

3.2.1. Effect of CN_{WAD} content

However the economic benefit margin of cyanide recovery over cyanide destruction increases as the concentration of cyanide in the CIP tails increases. Thus for a 150ppm CN_{WAD} concentration (always assuming 85% recovery) the annual operating cost (always for the same plant capacity) of the Cyanisorb process decreases to US\$0.62 (€0.48) million while that of an INCO SO₂/Air facility increases to US\$1.6 (€1.25) million. This is so because the cost of the latter is directly proportional to the amount of cyanide

destroyed while for Cyanisorb the credit is directly proportional to the cyanide recovered.

The differential between the two processing options though increases further as CN_{WAD} content increases as it can be judged from the data of Table 6 where estimates for 200 and 400ppm CN_{WAD} are given.

Table 5

Estimation of operating costs (in US\$) – Cyanisorb process – Option 2 (100ppm CN_{WAD}; 85% cyanide recovery assumed or 55.0kg CN recovered per hour)

Cost Item	Usage	Unit Cost (US\$ /kg)	\$/kg CN destroyed	\$/oz Au recovered	\$/yr (million)
NaOH (50%)	3.1kg/kg CN	0.3	0.92	1.58	0.40
H ₂ SO ₄ (98%)	1.5kg/m ³ or 1.8kg/tonne	0.1	1.7	2.8	0.70
CaO	1kg/m ³ or 1.2kg/tonne	0.1	1.1	1.9	0.48
Power	1060 kW*	\$ 0.052/kWh	1.0	1.7	0.43
NaCN (credit)	1.9kg/kg CN	1.3	(2.5)	(4.2)	(1)
Total			2.2	3.8	0.95

* for CIP flowrate = 61 l/m³/hr (refer to Table 1)

Table 6

The effect of CN_{WAD} content on operating costs (in US\$) – Options 1 and 2

Process	CN _{WAD} (ppm)							
	100	150	200	400	100	150	200	400
	(million \$/yr)				(\$/oz Au recovered)			
INCO SO ₂ /Air	1.1	1.6	2.0	3.9	4.4	6.3	8.1	15.
Cyanisorb	0.95	0.62	0.30	(1.0)	3.8	2.5	1.2	(4.0)

Taking the case of 200ppm CN_{WAD}, it can be calculated after considering the differential of the capital costs between the two options, 1 and 2, (US\$1.7 (€1.33) million for INCO SO₂/Air process and US\$8.5 (€6.63) million for Cyanisorb process) that the additional investment cost required by the Cyanisorb process can be paid back in 4 years. Hence Cyanisorb technology becomes a serious contender for mills generating high cyanide concentrations (> 200ppm) in their spent slurries. Of course, when longer payback periods can be allowed or other factors weigh heavily such as reduction of risk associated with cyanide transportation, Cyanisorb can be selected for even lower levels of CN_{WAD} (~100ppm).

3.3. Dual treatment with the Cyanisorb and the INCO SO₂/Air processes - Options 3 and 4

The Cyanisorb process alone cannot meet the criterion of <1 mg/l CN_T. To achieve this target two options were considered: (i) to treat the Cyanisorb Process effluent slurry with the INCO SO₂/Air process prior to discharging the effluent to the Tailings Pond (Option 3) or (ii) to discharge the Cyanisorb process effluent into the Tailings Pond and to treat the Tailings Pond discharge water with the INCO SO₂/Air process prior to its release to the environment (Option 4). The schematic of Option 4 is shown in Figure 5. Since it was determined in Option 2 that Cyanisorb technology becomes economical only at elevated cyanide contents, these calculations were made for the case of 200 CN_{WAD} content. It was further assumed to have 85% cyanide recovery (200 to 30ppm) (in both options) and a modest reduction of CN content (30 to 15ppm) due to natural degradation. It has to be stated, though, that the residual portion of cyanide tends to be in the form of moderately-strong metal cyanide complexes that decompose more slowly, hence may not be amenable to natural degradation.

The combined capital and operating costs for Options 3 and 4 are summarized in Table 7. Clearly, Option 4 is the more economical.

3.4. Natural degradation combined with treatment of tailings pond water - Option 5

In this case, the CIP tails are assumed to be directly discharged into the tailings pond. Natural degradation is assumed to bring the CN_{WAD} level down to 15ppm. The tailings pond water-overflow is treated by the INCO SO₂/Air process (350m³/h) (Similar estimates are expected with the other popular destruction process that of Degussa's copper-catalyzed H₂O₂ process). For this option the capital and operating costs are estimated to be only US\$400,000 and US\$350,000/yr (€312,000 and €273,000/yr), respectively. Clearly this is the most economic of all options.

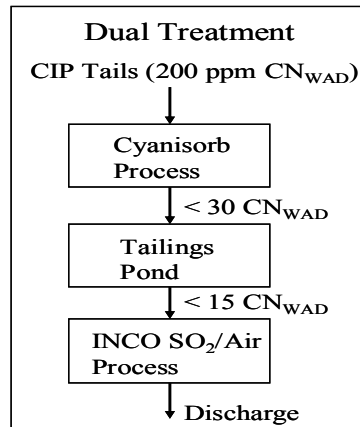


Figure 5. Schematic of dual treatment of CIP tails with the Cyanisorb process and the tailings pond water with the INCO SO₂/Air process (Option 4)

Table 7
 Combined capital and operating costs (US\$) for dual treatment - Standard case of 12,000MTPD and 200ppm CN_{WAD} - Options 3 and 4 (in US\$)

Option	3	4
Capital Cost	(\$ million)	(\$ million)
Cyanisorb	8.5	8.5
INCO-SO ₂ /Air	1.7	0.4*
Sub-total	10.2	9.0
Operating Costs	(\$ million/ yr)	(\$ million/yr)
Cyanisorb	0.37	0.37
INCO-SO ₂ /Air	0.46	0.22
Sub-total	0.83	0.58

* According to Devuyst (2004)

4. ENVIRONMENTAL ASSESSMENT

The above comparison of the two technologies gave emphasis on the economics of each one. A decision, however, cannot rely only on economic but also on a number of other factors including social and environmental ones. It is doubtful that natural degradation can continue to be widely used as method for cyanide detoxification. The risks of cyanide spills because of failure of tailings dams or the need to curtail the movement of cyanide shipments are expected to give an impetus to cyanide recovery technologies especially when high cyanide loadings are used. Further technological developments to solve on one hand the problems associated with slurry (as opposed to clear solution) treatment and on the other hand to lower the associated costs will ultimately help cyanide recovery to become more widely accepted. Recent efforts as are the development of SART (Sulfidization, Acidification, Recycle, and Thickening) and AFR (Acidification, Filtration, and RENEUTRALIZATION) cyanide recovery processes (Fleming, 2001) that according to their promoters offer cost advantages over cyanide recovery by AVR methods (as is the Cyanisorb process) due to the absence of the volatilization step are anticipated with interest in this regards. It must be kept, however, in mind that basically some residual cyanide will remain after recovery; hence, supplementary treatment for its detoxification will have to be always considered.

As far it concerns cyanide destruction technologies, it must be stated that several of those including the most popular among them, the INCO SO₂/Air process and Degussa's copper-catalyzed H₂O₂ process, produce cyanate (OCN⁻) (refer to Reaction 3) or fail to destroy thiocyanate (SCN⁻), both of which are faced with potential classification as toxic species. Such regulatory development will give further impetus to cyanide recovery technologies.

5. CONCLUSIONS

Cyanide recovery by the Cyanisorb process cannot alone meet the environmental standards of less than 1ppm CN_T unless the gold mill has a totally closed water balance, i.e. operates with no water discharge

- to the environment at all. In most of the situations a Cyanisorb treatment facility will require secondary treatment of the effluent to meet the environmental discharge criteria.
2. The economics of the Cyanisorb facility become attractive in cases of effluents with cyanide levels above 200ppm. In this case, payback in less than 4 years is anticipated.
 3. Cyanide destruction by the INCO SO₂/Air process remains the most effective and economic means to detoxify cyanide-laden waste slurries when CN_{WAD} levels are less than 200ppm.
 4. A combination of natural degradation and treatment of the overflow tailings pond water to destroy cyanide remains the most economic approach to gold mill effluent detoxification. Capital and operating costs are one order of magnitude lower than those required for treating CIP tails.
 5. In the future (or even today in certain parts of the world), however, factors such as, (i) increasing resistance to cyanide use/shipments, (ii) the requirement to operate certain mills with high cyanide loadings, or (iii) the potential classification of cyanate (OCN⁻) or thiocyanate (SCN⁻) as toxic substances are expected to give a considerable impetus to wide acceptance and commercialization of cyanide recovery technologies.

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